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THIRD INTERIM TECHNICAL REPORT ON USAFA SOLAR TEST HOUSE DESIGN--ETC(U)
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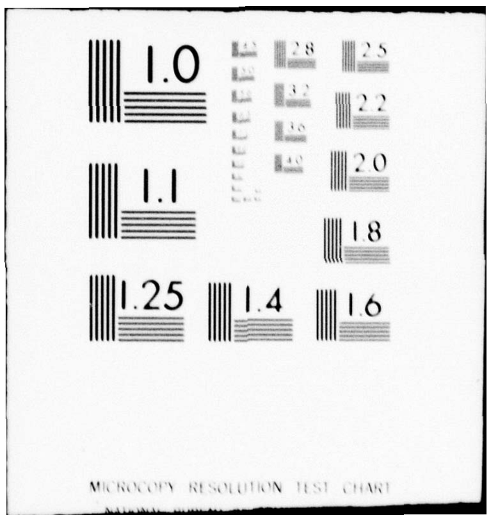
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CEEDO-TR-78-32

THIRD INTERIM TECHNICAL REPORT ON USAFA SOLAR TEST HOUSE--DESIGN PARAMETERS

SEPTEMBER 1978

CEEDO

CIVIL AND ENVIRONMENTAL
ENGINEERING DEVELOPMENT OFFICE
(AIR FORCE SYSTEMS COMMAND)
TYNDALL AIR FORCE BASE
FLORIDA 32403

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER CEEDO-TR-78-32	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Third Interim Technical Report on USAFA Solar Test House--Design Parameters		5. TYPE OF REPORT & PERIOD COVERED May 1977--April 1978
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Anthony Eden John T. Tinsley		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Department of Civil Engineering, Engineering Mechanics & Materials United States Air Force Academy, CO 80840		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS P.O. DTC-8-108
11. CONTROLLING OFFICE NAME AND ADDRESS Civil and Environmental Engineering Development Office (CEEDO), Tyndall AFB, FL 32401		12. REPORT DATE September 1978
		13. NUMBER OF PAGES 152
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE N/A

16. DISTRIBUTION STATEMENT (of this Report)

Approved for Public Release; Distribution Unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

ORIGINAL CONTAINS COLOR PLATES: ALL DDC REPRODUCTIONS WILL BE IN BLACK AND WHITE

Solar Energy	Thermography
Solar Heating	Solar Design Parameters
Retrofit	

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report describes the continuing performance of the first retrofit-constructed, solar-heated facility in the USAF, the Solar Test House at the USAF Academy. Continued efforts to improve the performance have been a further reduction of the storage tank volume and installation of make-up water system to work in conjunction with the bleed air valves. The thermography studies started during the previous research period were completed and the techniques of using this advanced procedure for displaying flow → next page

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patterns validated. The data analysis for the Solar Test House shows the improvement to the efficiency of the total system's ability to supply the thermal energy to the structure. Finally, the various parameters used to design the solar energy systems originally are analyzed and shown to be valid for this application.

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THIRD INTERIM TECHNICAL REPORT ON USAFA SOLAR TEST HOUSE DESIGN PARAMETERS,

Rept. for May 77-apr 78,

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by

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Captain John T. Tinsley

Technical Report TR-

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FOREWORD

This report was prepared by members of the Department of Civil Engineering, Engineering Mechanics and Materials (DFCEM), USAF Academy, Colorado. The work was initiated under Civil and Environmental Engineering Development Office (CEEDO) Project Order Number DTC-8-108. The project investigators were Captain Anthony Eden, Captain John T. Tinsley, Captain Kenneth Cornelius, Captain Joel Benson, Captain William J. McClelland, and Captain Gregory Riggs. Project Director was Colonel Wallace E. Fluhr.

This report covers work accomplished from May 1977 to April 1978. This manuscript was released by the authors for publication in September 1978.

The authors wish to acknowledge the support of personnel assigned to the 7625th Civil Engineering Squadron and the Department of Instructional Technology at the Air Force Academy. Specifically, the authors are indebted to Mr. John Slocum, Mr. Jack Whelton, Mr. Thomas D. Fultz, Captain Jerry A. McKee and family, Second Lieutenants Robert G. Mansfield, William F. Schauffert, and Peter W. Gray, Cadet First Class Michael L. Baumgartner, SrAmn Celeste Augustine and especially Mrs. Missy McClelland.

The authors are grateful to Mrs. Penny Grayson for her professional drafting assistance and her dedicated efforts in proofing and finalizing the manuscript.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

This interim technical report describes the continuing performance of the Solar Test House at the United States Air Force Academy (Figure 1-1) from May 1977 to April 1978. This report is the third in a series of reports aimed at evaluating the data collected by the data and control system at the house. Data analysis, evaluation of modifications made to improve the performance of the various systems, evaluation of improved overall efficiency, and design parameter analysis are the main points of this report. The first interim technical report, FJSRL TR-76-0008, September 1976 [8], should be referenced for details on original system construction. The second interim technical report, FJSRL TR-77-0016 and CEEDO-TR-77-34, September 1977 [3], should be referenced for details on subsequent changes in the original construction and initial data analysis.

The project coordination with the Air Force Systems Command rests with the Civil and Environmental Engineering Development Office (CEEDO) which is Det 1 ADTC (AFSC) at Tyndall AFB, Florida.

This report should increase the base of information already established by the first two interim technical reports for use by engineers in the field. By discussing the difficulties observed with an operating solar energy system, by analyzing the effectiveness of the attempted corrections, by illustrating the efficiencies possible

Figure 1-1. USAFA Solar Test House

from such a system, and by analyzing the various design parameters, this report can be referenced as a measure of the performance and a source of possible solutions to future problems. In this approach, emphasis will be placed on observations of the researchers in areas difficult to quantify. Data and its analysis are included to substantiate actual results.

1.2 Project Objectives

The objectives of this project remain:

a. to develop baseline design criteria to support future Air Force solar energy programs;

b. to obtain sound design, construction, and operations and maintenance experience in real property-oriented solar energy systems;

c. to obtain sound cost data on such solar energy systems upon which future economic effectiveness models may be based.

1.3 Approach

The approach taken during the first two years of operation of this solar energy system was that of observing the various components in operation and the effects of the parameters on overall efficiency. The analysis of the data collected was handled through the computer programs designed to give the researchers the most vital information at first glance. Detailed analysis of the more technical areas were covered by further computer analysis or by assigning those areas to cadets as special projects. This series of priorities led to emphasis being placed on maintaining the system at top performance and addressing

the problems with performance directly as they appeared. As will be discussed in this report, various attempts at improving that performance were successful, and the data analysis will show the extent.

The units used in this report are a mixture of English and SI. The summaries listed for monthly and yearly performance are in SI units. Where appropriate, both types of units are given; however, due to common practice in the construction industry, heat transmission and resistance coefficients are listed in English units as well as degree days of heat load analysis.

1.4 Contents of the Report

This report covers the period of data collection from May 1977 to April 1978. The overall performance period is the entire operating time of the system to allow discussion of improvements in efficiency from one year to the next. The control system was modified to allow measurement of previously unsensed energy contributions and the inclusion of a new mini-micro control system. Thermography is discussed to illustrate the application of this new technique to make improvements in collector performance. An extensive section of the report covers the data obtained during operation and its monthly, yearly, and overall significance. Design parameters used to originally design the solar energy system are discussed with emphasis on analyzing their accuracy. Finally, conclusions reached during this period of operational research and recommendations for the future are listed to illustrate the scope of continuing research at this laboratory.

CHAPTER 2

SYSTEM AND OPERATION CHANGES

2.1 Introduction

The Solar Test House energy systems functioned very well during the year of operation. Only minor changes were needed to improve the performance or increase efficiencies. These changes discussed in this section include the bleed air line on the roof array, the make-up water system, ground array tilt change, tank mass reduction, flow rate calibration, exterior entrance, and the new evacuated tube collector system.

2.2 Bleed Air Line on Roof Array

After the success in eliminating air trapped in the ground array by the bleed air line installed there, a similar line was installed on the roof array. Together with the same flow reduction reported in the second interim technical report, this line was designed to release any air which became trapped in each collector's upper header. This bleed air line consists of 1.27 cm O.D. (1/2 in. O.D.) copper tubing connected by flare fittings to the upper left corner of each collector (Figure 2-1). These lines then run to the next collector to the left so that one line connects all the panels in each cluster (Figure 2-2). Finally, the line terminates at a bleed air valve specified to 525 kPa (75 psi). The entire system is more complex than the ground array system due to the higher elevation of the roof array definitely causing any air in the

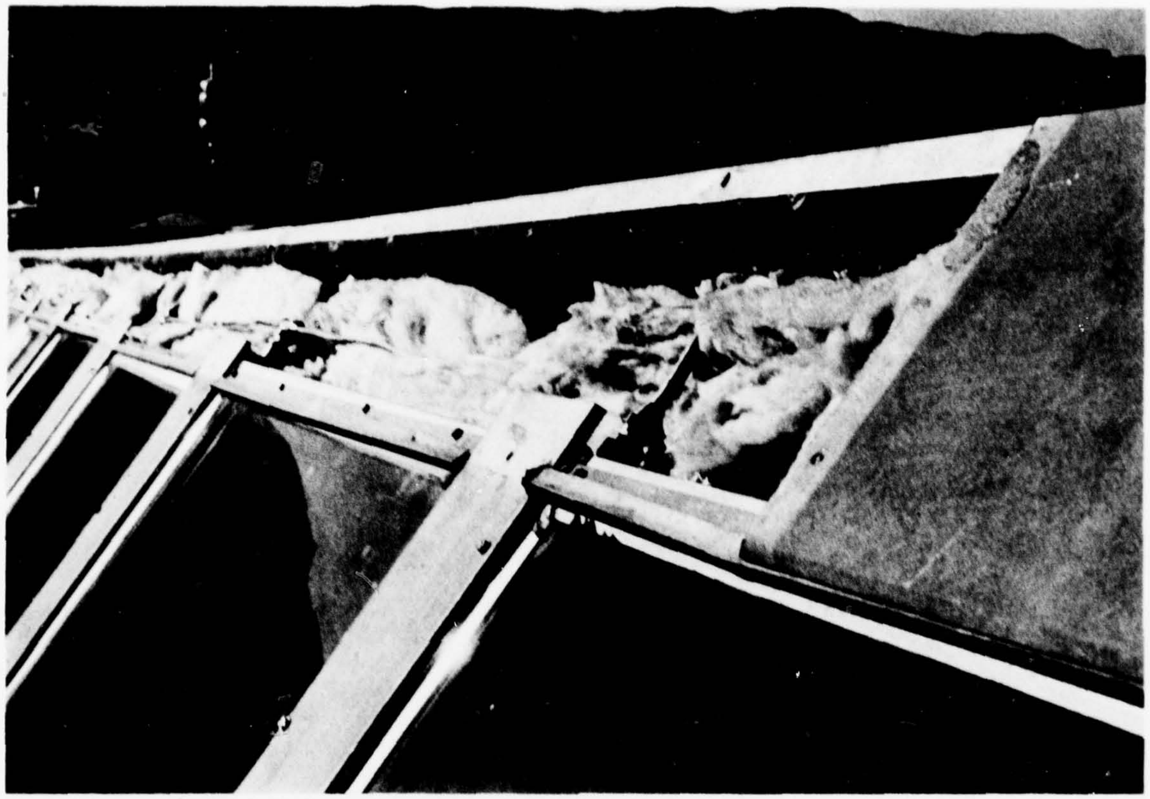

Figure 2-1. Roof Array Bleed Air Line
(Looking West)

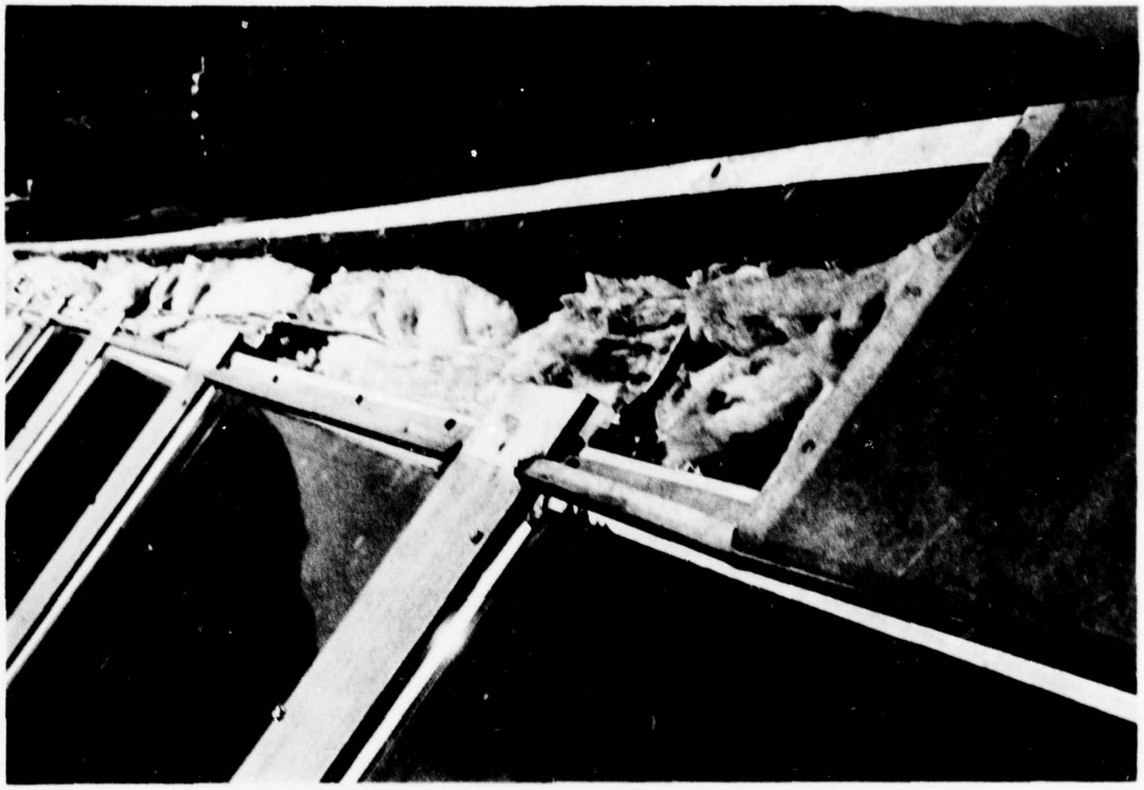

Figure 2-2. Roof Array Bleed Air Line
(Looking East)

collectors to gather there. The system functions by allowing the air to escape when it begins to be trapped in the roof array panels. Any air in the clusters therefore has a direct route out of the system.

Initial operation of the roof array bleed air line appeared successful; however, problems began to occur. The air was being vented by the bleed air valves, but there was no way to add fluid to the system to replace it. The minor leaks that existed in the system let in more air over a long period of time. The replacement of the air by water was not being accomplished. To increase the effectiveness of this system, the make-up water system, discussed in the next section, was added.

2.3 Make-Up Water System

A make-up water system was added to the plumbing design in the basement of the Solar Test House. This system allows the easy addition of city water to the ground array and roof array flow loops. As shown in Figure 2-3, the make-up water is piped past a spring-loaded, one-way check valve to pressure reducing, regulator valves connected to each collector fluid loop. These regulators reduce the city water from 420 kPa (60 psi) to 140 kPa (20 psi). Originally the gate valves were left open and the collector fluid loop pressure was maintained at 140 kPa. At night, when the fluid in the loops contracted and air would be drawn into the plumbing, the make-up system would maintain positive pressure and supply water on demand. Thus, any air not bled out of the system by the bleed air valves would not be increased by additional incoming air. A check on how

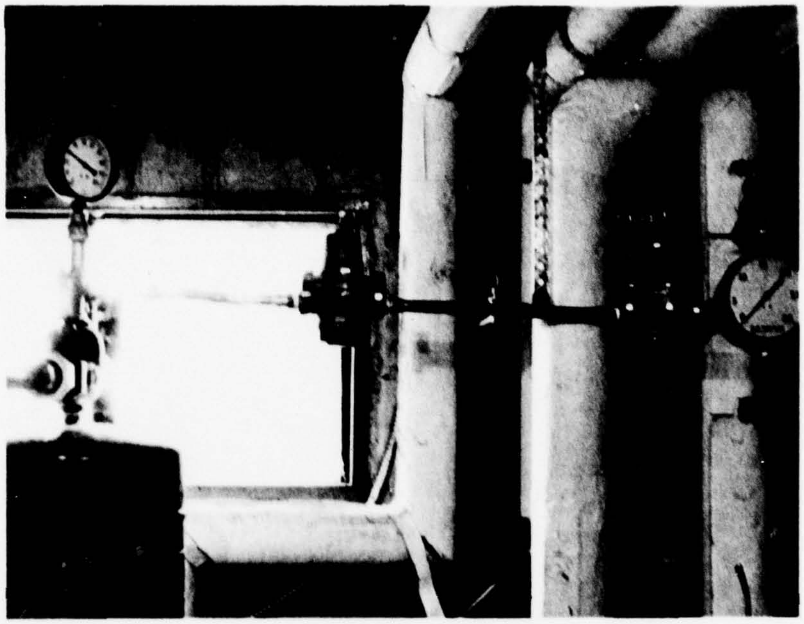

Figure 2-3. Collector Water Make-Up System

much water was being added to offset the leaks was done by the monthly sampling of the array's fluid. Tests were conducted to monitor the ethylene glycol content, as well as the pH. This system functioned perfectly from 24 May 1977 until 3 January 1978.

The make-up water line/bleed air vent combination worked in theory as long as there were no massive leaks in the system over a short time period. If one would occur, and go unnoticed by the researchers or occupants, the solution of ethylene glycol and water would begin to dilute. If cold temperatures were encountered during this time, freezing of the solution could result. This sequence of events occurred about 2 or 3 January 1978. A connection in the bleed air line on the ground array broke, allowing a steady loss of fluid. The leak was not noticed by any of the research personnel. Finally, the percentage of ethylene glycol dropped to a low enough level for freezing at -6°C (22°F). A larger leak occurred at this time as the fluid froze. Finally, one of the ground array collectors, the eighth from the left, broke and a catastrophic leak was noticed due to a large build-up of ice under the ground array just after a snowstorm. The percentage of ethylene glycol was checked and found to be 7 per cent. One of the spare panels was installed on the ground array in place of the broken one and the bleed air line was repaired. The automatic functioning of the make-up water system was stopped by closing the gate valves. Continued operation is now accomplished by a weekly check of the pressure in the collector loops and any necessary addition of water at night. Any abnormal

amounts of pressure drop or water addition is noted as evidence of further leaks.

A double protection level exists to prohibit the collector fluid from entering the city water system. The pressure reducing, regulator valves and the one-way, spring-loaded check valve perform this function. The bleed air line/make-up water system combination does solve the problem of trapped air in the collectors.

2.4 Ground Array Tilt

At the beginning of spring 1977, the ground array was still set at 60° with respect to the horizontal. This angle had been used to more closely align the panel surfaces with the low solar angle in winter. On 24 May 1977, the ground array was again placed at 45°. This allowed better collection of solar energy as the sun's path moved steadily higher in the sky.

The roof array (whose angle is 52°) and the ground array had never been placed at the same tilt since the start of the research project. This experiment was finally started on 1 October 1977 when the ground array was moved to 52° slope (Figure 2-4). This setting would allow the determination of any differences in a roof- or ground-mounted solar energy collector system due to their positions on or behind the structure. With both arrays at the same angle, they would receive exactly the same amount of insolation throughout the test. The third heat exchanger in the ground array loop and its effect could be more closely observed. Results of this change are discussed in Section 5.3, Collector Performance.

Figure 2-4. Ground Array at 52°

2.5 Tank Mass Reduction

After the reduction in storage tank volume in July 1976, the storage tank mass was still considered too large. To further reduce the 6814 liters (1800 gallons) of water, the foot valves on the intakes to the heating coil and domestic hot water heat exchangers were lowered to the top of the storage tank heat exchangers. When the storage tank was refilled to this new level in August 1977, approximately 5400 liters (1400 gallons) became the new storage volume.

Once again, the immediate effect of this change was the predicted faster reaction of the storage tank to the high temperature water from the collector loops. The tank temperature could now raise quickly to a higher, more usable range. This in itself allowed more use of the energy collected for house and domestic water heating.

Table 2-1 illustrates the effects of the lowered tank volume on the rise of the storage tank temperature (ΔT). The dates chosen

6800 Liters				5400 Liters			
DATE	ΔT (^oC)	MJ COLL	DD (^oF)	DATE	ΔT (^oC)	MJ COLL	DD (^oF)
10 Feb 77	13	697	29	23 Feb 78	14	597	30
11 Feb 77	5	383	30	6 Feb 78	5	248	31
15 Feb 77	7	455	40	15 Feb 78	7	374	41

Table 2-1. Effects of Tank Volume Reduction

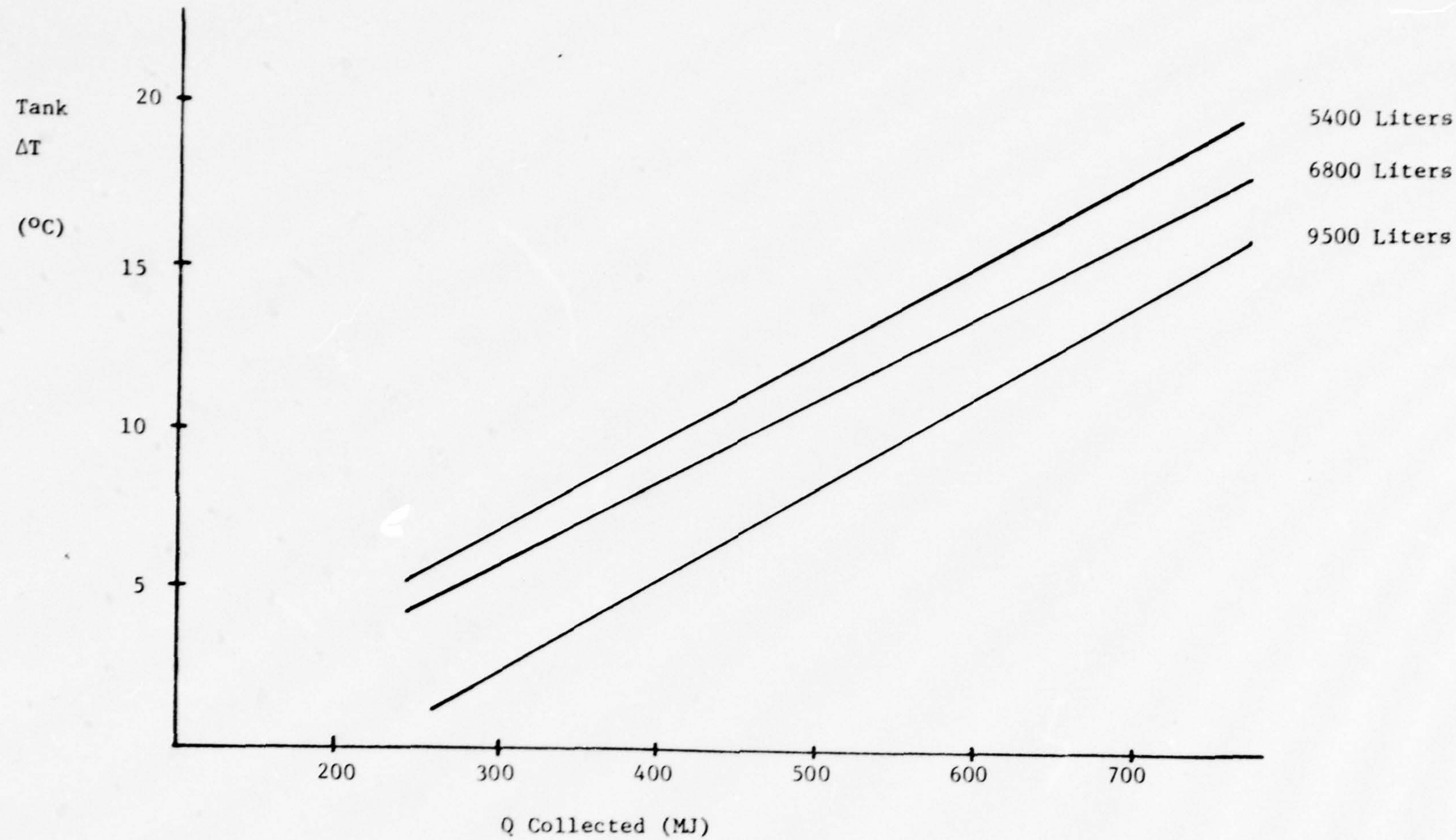

Figure 2-5. Tank Volume Effects on Storage Temperature Rise

were before and after the latest volume change. Less energy was required to obtain the same temperature rises after the volume reduction. This was significant in that it took into account the ambient temperatures that existed by the comparable degree days (DD). The temperature rises were the result of less water mass and not less severe weather conditions.

Figure 2-5 shows graphically the effect of varied storage tank volume on the storage temperature rise over the entire period of research.

2.6 Flow Rate Calibration

Throughout the time of the collection system operation, the flow rate determination has been a difficult task. The initial calibration of flow rate to valve positions was accomplished and the results were included in the data analysis computer program. However, as the valves operated over the years, the calibration became more and more suspect. An experiment was conducted using the annubars already installed and a diaphram, dynamic pressure meter. The results obtained were unsatisfactory. The pressure drops through the diaphram were apparently too small to accurately gage the flow rate consistently. This realization led directly to the potter meters being reinstalled and calibrated to the flow rate by an electronic frequency counter. The results are shown in Table 2-2. The actual flow rates were much lower than the original calibration had shown. The ground array (GA) and roof array (GA) flow rates varied one from the other at the same microprocessor command. A new subroutine in the analysis program was added to reflect these

conditions and the roof array valve was adjusted to allow approximately the same flow rate as the ground array at the microprocessor command of 208. This situation forced a re-analysis of the data collected after the half-open position was commanded as the maximum allowable. April 1977 was re-analyzed and is included in Section 5.2. A new electronic circuit for flow rate measurement is discussed in Section 3.3. This circuit will allow direct reading of the flow rate and eliminate the calibration process.

VALVE CALIBRATION TO
FLOW RATE TEST
13 December 1977

Microprocessor Command	GA (gpm) Original	RA (gpm) Original	RA (gpm) Adjusted
0	0	0	0
20	0	0	0
40	1.2	0	0
60	1.2	0	0
80	1.2	0	0
100	1.5	0	1.2
120	1.8	0	1.5
140	2.9	0	2.4
160	3.0	0.5	3.0
180	3.3	1.0	3.3
200	4.0	2.0	3.6
220	5.8	7.0	4.0
240	12.0	8.0	5.4
250	12.0	9.0	6.5
255	12.5	9.0	7.0

Table 2-2. Valve Calibration

2.7 Exterior Entrance

Occupant comfort has always been a primary consideration of the research group. After a number of years of operation of the solar energy systems within a house environment, it was decided to relieve some of the interruptions to family life by installing another entrance into the Solar Test House. This entrance was designed to allow quick, direct access into the mechanical room in the basement without going through the main living areas. Two views of this exterior entrance are shown in Figure 2-6.

The construction of the exterior entrance required cutting into the existing wall structure of the house. The location allowed direct access to the landing on the stairs leading to the basement. This required cutting into the brick wall on the west side of the house. On 26 September 1977, the doorway construction was started. The research group observed the initial cutting into the wall in order to note the condition of the urea foam that had been inserted there on 2 February 1977. The urea foam was revealed when the interior wall was pulled down. It was still perfectly filling the cavity between the interior wall and the original rock wool insulation. There were very few voids noted between the urea foam and the 2x4 construction. Slight moisture marks (stains) were noted at the bottom of the studs but no evidence of dry rot was observed. The rock wool insulation was still in place with no moisture damage or moisture in it. The stains on the bottom of the wall could have been caused by the watering of

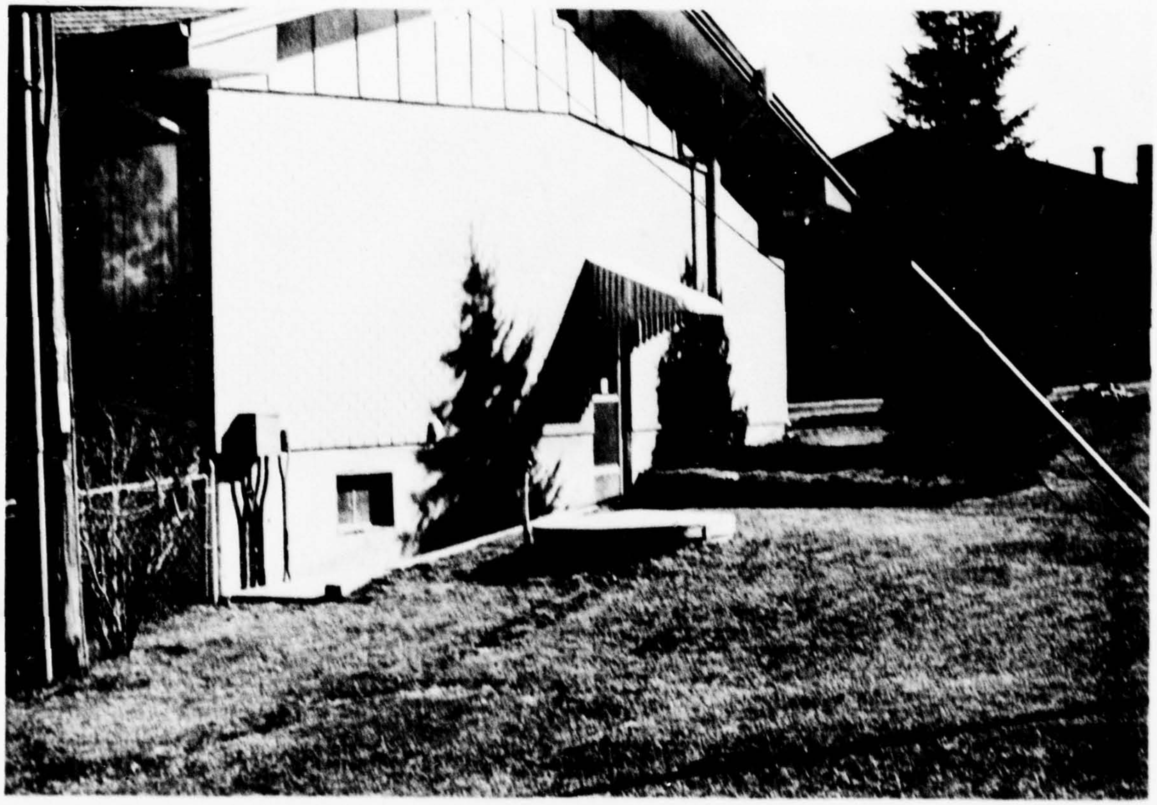

Figure 2-6a. Exterior Entrance

Figure 2-6b. Exterior Entrance
(Looking East)

grass outside and the sprinkler spraying the water onto the wall. The urea foam, therefore, had not deteriorated at all, had completely filled the cavity, and had not caused any damage to the wall due to the water pumped in with it during insertion.

The exterior entrance was constructed with a standard door, weather stripping and a storm door. An awning offers protection from rain and snow. A vestibule was not constructed over this entrance due to its cost and the use of the door only for access during research activities.

2.8 New Evacuated Tube Collector System

After gaining experience with the parameters involved in operating the flat-plate collector system on the roof and ground arrays, the research group proposed to investigate the operations of evacuated tube solar energy collectors. These collectors have been developed in the past few years by various manufacturers to supply higher temperature hot water than the flat-plate collectors are capable of doing while still maintaining a high efficiency. This higher temperature water is necessary in some energy systems to power air conditioning equipment such as absorption refrigerators. Although the Solar Test House is not programmed for research into solar energy cooling systems, it is felt research could still be conducted into the operations and maintenance of an evacuated tube system. These collectors are beginning to be used in various large systems in the Air Force. Practical applications research and experience could be valuable to allow determination of and solution to typical problems.

After extensive investigation into the different types of these collectors [4], the ones made by General Electric were chosen. The TC-100 Vacuum Tube Solar Collector (Figure 2-7) is representative of the current state-of-the-art for evacuated tube collectors. Besides being less expensive than other collectors considered (Owens-Illinois), the TC-100 has the following advantages:

a. Thermal energy is removed from the glass tubes by an independent fluid system entirely contained in metal, which allows the system to continue operating in the event of glass breakage.

b. Each tube lies in its own tray which serves as a reflector (Figure 2-8).

c. Improved reliability by omitting glass-to-metal seals.

d. Ten finned loops are interconnected to form a serpentine structure of ten loops in series (Figure 2-9). This design creates sufficient collector pressure drop to drive the fluid through the serpentine without trapping air and to insure uniform flow distribution in a row of collectors mounted in parallel to a common header [4]. The final selection was also influenced by the fact that no research has been performed on the TC-100 in the Colorado area, while the Owens-Illinois collectors are being used by Colorado State University on Solar House III. All these factors led to the selection of the TC-100 for research at the Academy.

In order to install these collectors and still be able to have quick access to them, the ground array will be modified as shown in Appendix A during the summer of 1978. By modifying just the

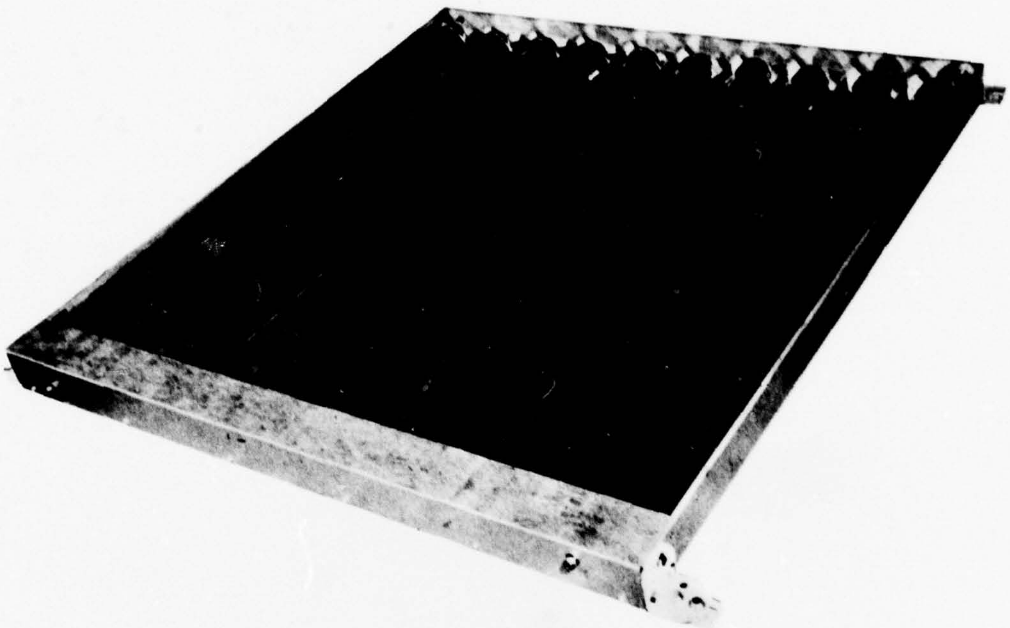

Figure 2-7. Vacuum Tube Solar Collector [4]

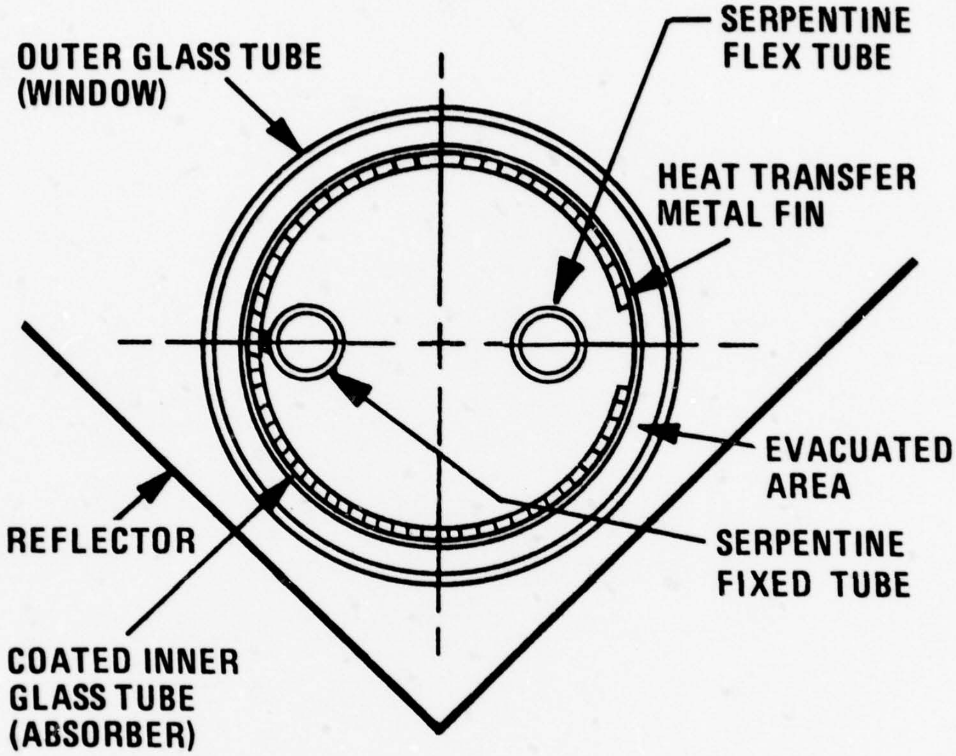

Figure 2-8. Cross Section of TC-100 Active Elements [4]

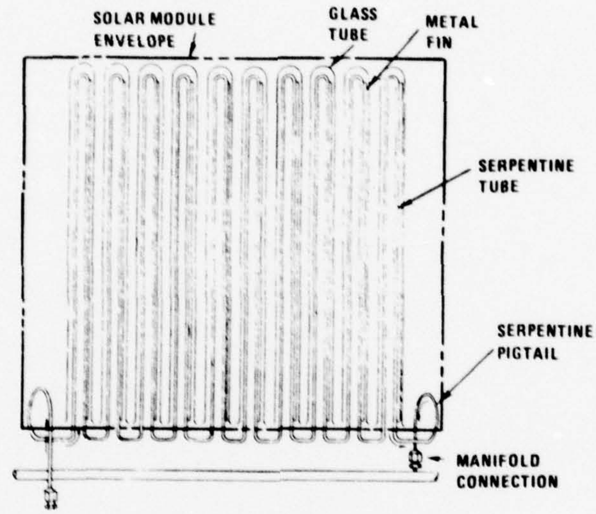

Figure 2-9. Serpentine Heat Exchanger Assembly [4]

ground array, a direct comparison can be made between flat-plate collectors on the roof and evacuated tube collectors on the ground. The microprocessor will be reprogrammed to change slightly the control algorithm for inclusion of special checks for evacuated tube collectors. Due to the rapid ability of these collectors to heat water to very high temperatures, a check must be made on the collector temperature before sending water out to the array after a power failure on a sunny day. This and other peculiarities will be observed and the capabilities of the current plumbing system determined for future Air Force use of the evacuated tube collectors.

CHAPTER 3

INSTRUMENTATION AND CONTROL SYSTEM

3.1 Introduction

The instrumentation and control system has performed very well during the period of this report. Minor programming changes were made to improve data gathering and transfer reliability but, in general, no major changes were made. The main effort has been spent on three systems yet to be installed: hot water preheat measurement system, flow rate measurement system and a new mini-micro system controller.

3.2 Hot Water Preheat Measurement

The solar collection system provides energy for space heating and domestic hot water preheating as described in the first interim technical report. Measurement of that portion of energy provided to the hot water system has not been accomplished in the past but rather a comparison was made with the Control House. To enable the researchers to obtain more accurate data on the performance of this system, an electronic measurement system was designed and built.

Figure 3-1 shows the mechanical layout of the hot water preheat system.

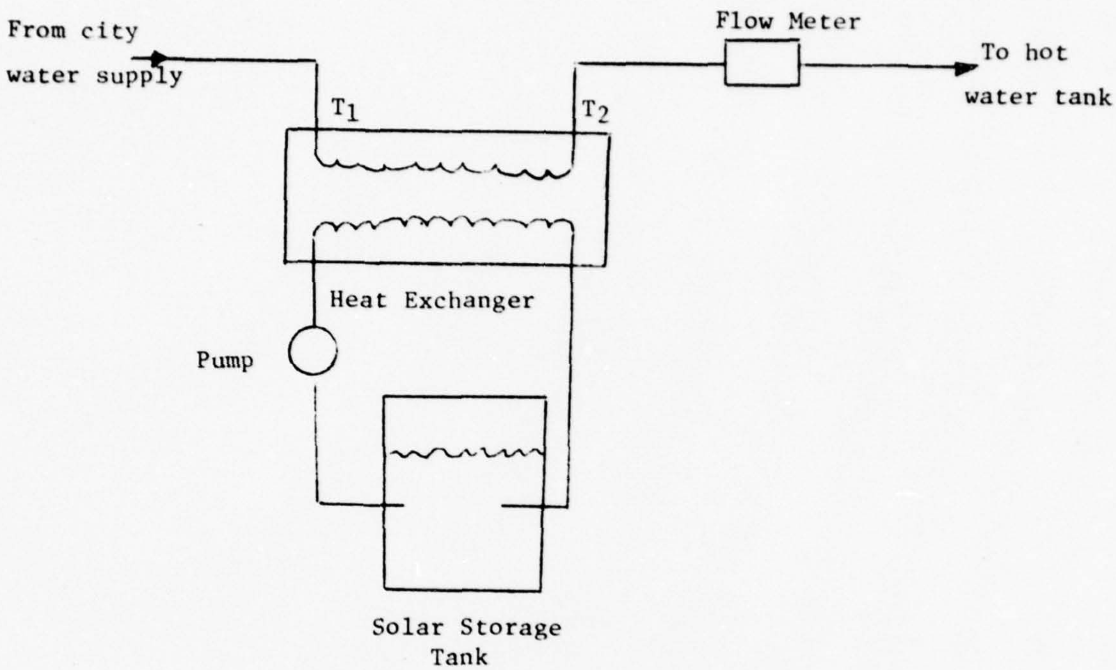

Figure 3-1. Hot Water Preheat System

The equation describing the net heat flow rate to the domestic hot water system is:

$$\dot{Q} = \dot{M}\, C_p \;\; \Delta T$$

where:

$\dot{Q}$ = Heat Flow Rate

$\dot{M}$ = Mass Flow Rate

C_p = Specific Heat at Constant Pressure

$\Delta T = T_2 - T_1$

Over a given time interval, with C_p constant, the total energy gained by the domestic hot water system is:

$$Q = C_p \int_{t_1}^{t_2} \dot{M}\, \Delta T \, dt$$

If the time interval is small, a reasonable approximation to this equation can be obtained by assuming ΔT constant, thus:

$$Q = C_p M \Delta T$$

In this particular application, ΔT is obtained from $T_2 - T_1$, and M from integrating the flow meter output over a one-second interval. A block diagram of the actual electronics system designed for this measurement system is presented in Figure 3-2.

The temperatures T_1 and T_2 are measured by two Relco Products, Inc., semiconductor temperature sensors placed in the system as indicated in Figure 3-1. These temperature voltages are input to an op-amp subtractor to give $T_2 - T_1$ or ΔT. A positive ramp generator with a period of one second is one input to an op-amp comparator

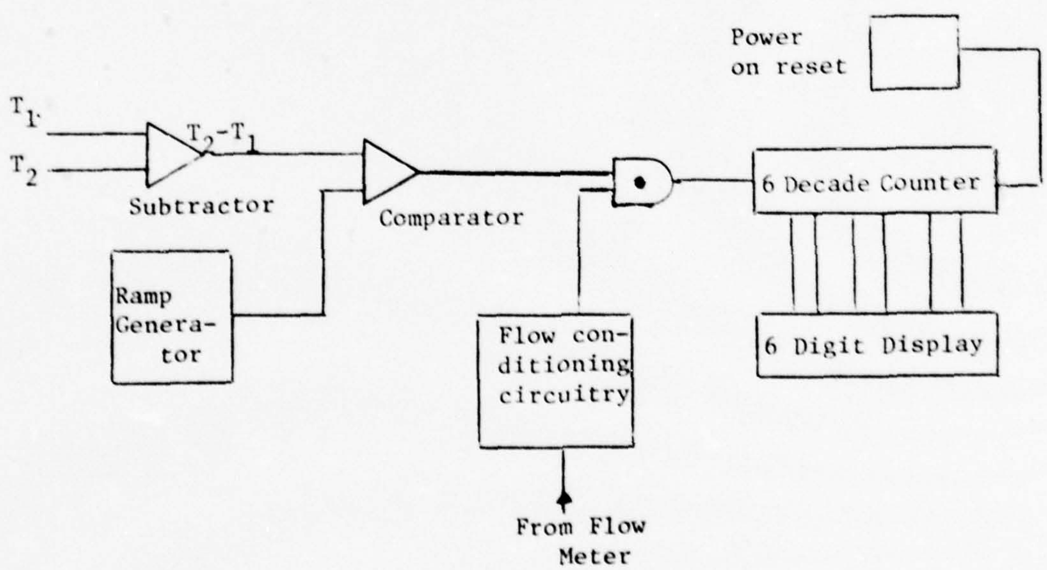

Figure 3-2. Hot Water Preheat Measurement System

with ΔT as the other input. The comparator output is thus a square wave with a one-second period whose pulse width is directly proportional to ΔT.

The potter meter output is a sine wave voltage whose frequency is directly proportional to the flow rate. This signal is input to a signal conditional circuit which provides impedance matching, amplification, and outputs a square wave.

The comparator output and conditioned flow meter output are then input to an "AND" gate, giving an output which is directly proportional to $\dot{Q}$. If this output is integrated (counted), a running total of the net heat transferred, Q, is obtained.

The six digit output display thus represents a running total of the net energy provided to the hot water preheat system by solar energy. To preclude erroneous readings due to unmonitored power failures, a power-on reset circuit clears the counters and flashes the display until the reset button is pushed.

3.3 Flow Rate Measurement System

The flow rate through the collectors is controlled by a variable valve in series with the pump. One of 256 positions between full open and closed is selected by the microprocessor depending on the values of the various control parameters. Originally, a valve calibration curve was made, thereby allowing the flow rate to be determined by the data analysis program by knowing the selected valve position. Due to play in the valve motor gears, slippage of the feedback potentiometer and other errors in the connecting linkage,

this method of determining flow rate has proven to be less than desirable. To measure more accurately and reliably the flow rate through the collectors, an electronic circuit was designed and built to sample the flow rate over a time interval and input the results to the microprocessor for recording.

A potter meter was installed in both the ground and roof array loops. The sinusoidal voltage output from this flow meter is input to the circuitry shown in Figure 3-3.

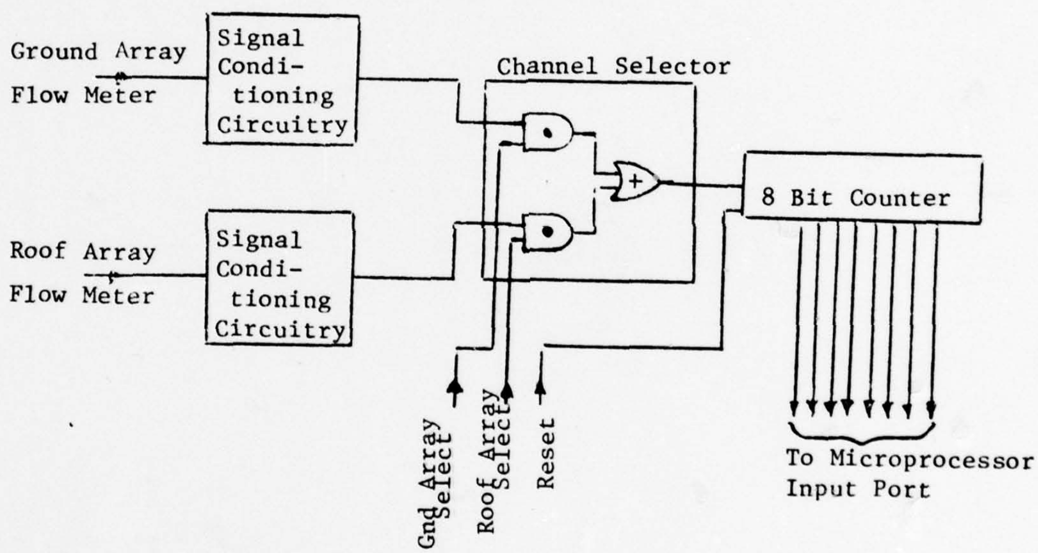

Figure 3-3. Flow Rate Circuitry

The signal conditioning circuitry provides impedance matching and amplification of the flow meter signal and outputs a square wave whose frequency is directly proportional to the flow rate. The channel selector merely provides a means for the microprocessor to select and count the flow from one array at a time. An eight bit, binary counter with reset capability is used to count the flow meter

signal over a small time interval. The microprocessor subroutine used to read the flow is presented in flow chart form in Figure 3-4.

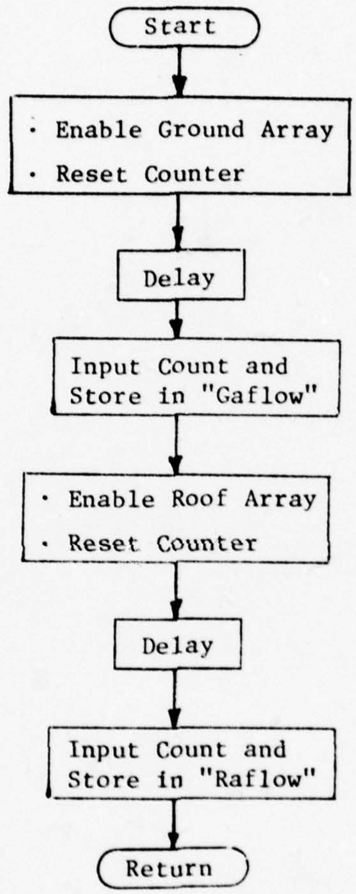

Figure 3-4. Flow Rate Subroutine

3.4 Mini-Micro System Controller

The Solar Test House facility is a research project and as such has an extensive and elaborate data gathering and control system. One of the main purposes of this project is to recommend design parameters and systems for use by the Air Force in actual applications. With this in mind, a "mini-micro system controller" was designed and

will be installed to obtain design parameters and operational data on an actual solar system controller.

Most solar controllers commercially available today are simplistic in design and limited in capability. They are primarily built using discreet components, i.e., transistors and simple integrated circuits. The single most limiting capability of these controllers is the inability to make control algorithm changes. The controller essentially has to be redesigned and rebuilt for even minor changes. It is for this reason that a project was undertaken to design a microprocessor-based solar controller.

Figure 3-5 is a functional block diagram of the prototype controller. It is composed of three basic integrated circuits: the

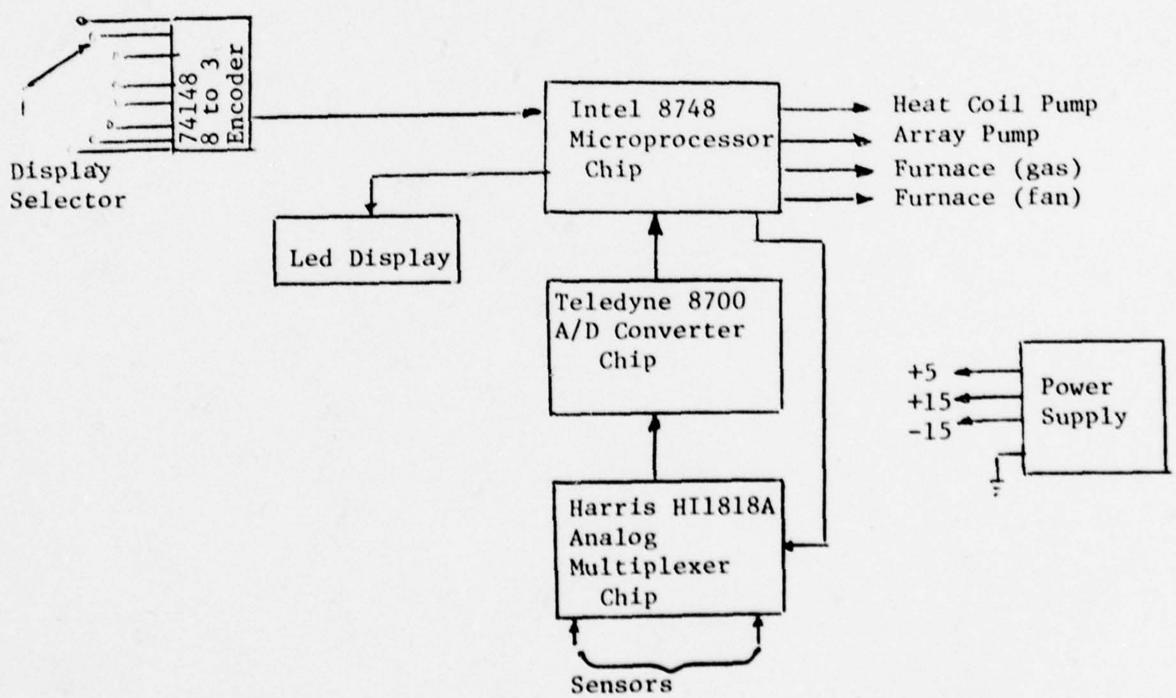

Figure 3-5. Functional Block Diagram of Prototype Controller

microprocessor chip; the analog to digital converter (ADC); and the analog signal multiplexer (AMUX). The microprocessor sends an address to the AMUX which gates the appropriate sensor signal to the ADC. Output from the ADC is an eight bit binary representation of the sensor reading. The control program internal to the microprocessor uses the sensor readings to control the outputs to the furnace heat coil pump, roof array pump, furnace gas valve and fan motor. Additional circuitry required are the display and display selector switch used to command the microprocessor to display sensor readings; and the power supply to provide $\pm$ 15 VDC for the sensors, ADC and AMUX, and + 5 VDC for the microprocessor and display. Any sensor providing a 0-10 VDC output may be used. Interface between the microprocessor and the pumps, gas valve and fan motor is via a solid state AC switch such as International Rectifier switch #D1202.

The goal of this project was to design a controller, when mass produced, to cost under $100 excluding sensors and interface switches. In addition, the system must have the capability for easy program changes. The INTEL 8748 microprocessor chip accomplishes these goals with state-of-the-art technology.

CHAPTER 4

THERMOGRAPHY STUDIES

4.1 Introduction

Thermography is the application of infrared photography to the problem of detecting thermal energy emissions from various sources. It is usually used in the analysis of heat losses from structures and underground pipelines as well as hot spots in electrical distribution systems. Thermography studies of the solar collectors were started in the second year of operation to attempt to apply this technique to assist the researchers in discovering flow patterns through the clusters of panels. This section covers the results of the thermography studies during this past year of research.

4.2 Application of Techniques to Roof Array

After the correlation of absorption surface temperatures on the ground array to thermographic data, the thermography techniques developed by the research group were applied to the roof array. These techniques allowed observation of the flow patterns in the roof array collector clusters in detail and eventually led to correction of flow blockages [7].

Figure 4-1a shows a typical thermograph of the first cluster of the roof array. This picture indicates a normal flow pattern with a temperature difference of approximately 30°C between the first and third panels. The fourth panel in the picture, which is the first one of the second or next cluster, is the same temperature as

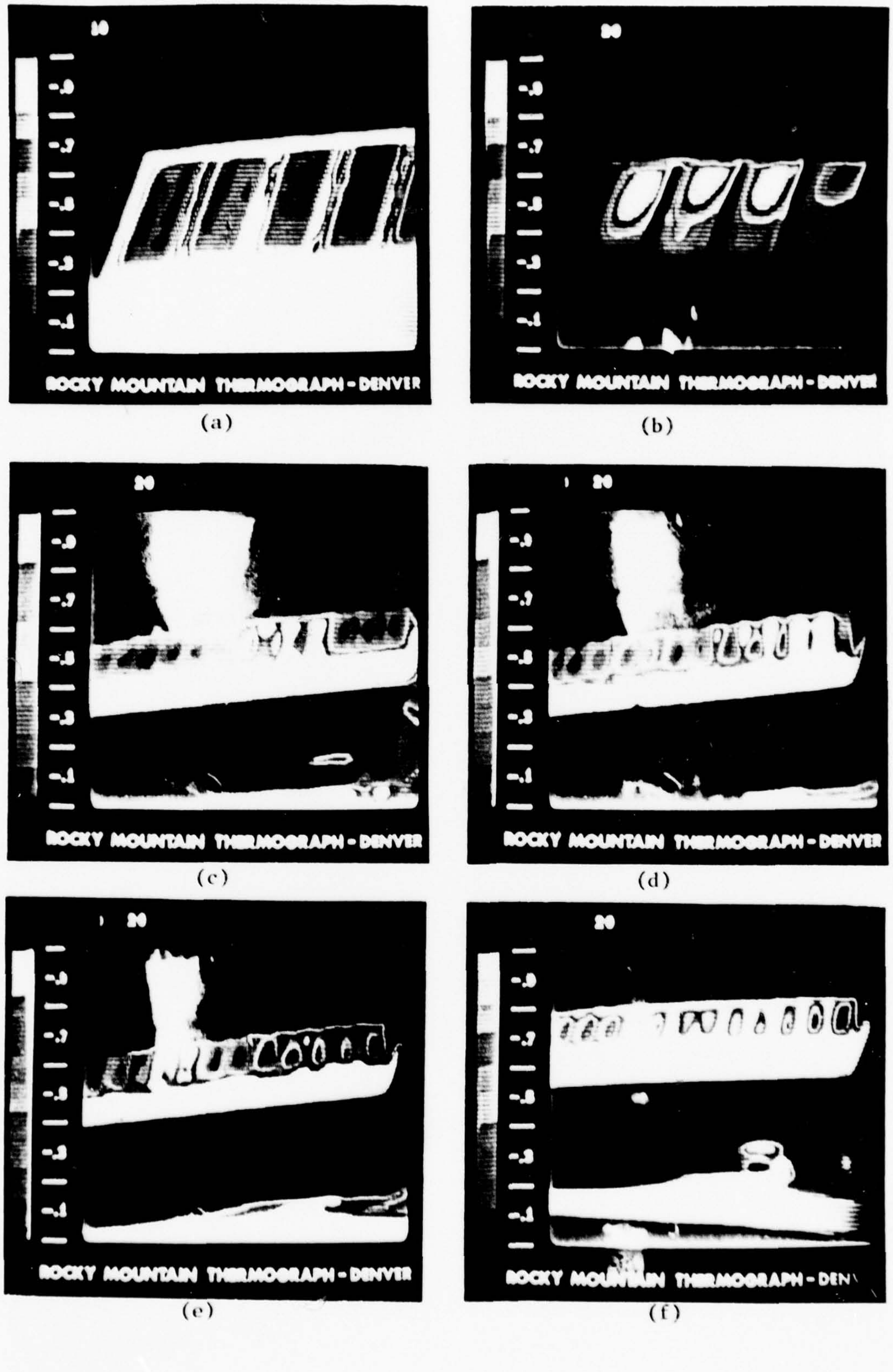

Figure 4-1. Thermography Studies

the first panel in the first cluster. Flow through these panels is therefore normal and apparently even.

However, the roof array did occasionally experience blockages due to trapped air. Figure 4-1b shows a telephoto picture of such a blockage. The highest temperatures seem to exist in the areas where air would stop flow and fluid would flash to steam. Once the first panel in this cluster is blocked, the entire cluster stops transferring solar energy to the collector fluid and the incoming solar energy heats the absorbing surfaces. To clear this blockage, an experiment was conducted to observe the effects of manual operation of the flow valves on the roof array.

Figure 4-1c shows the blockage of the roof array in the third cluster. Due to the hydraulic situation in the plumbing at the collectors and the head losses in the supply lines, the third cluster was more prone to gather trapped air than any of the others. This cluster was left fully open and the fourth cluster was shut down manually by closing the gate valves to the supply and return headers. Figure 4-1d indicates that the fourth cluster absorbing surface temperatures were beginning to rise. The temperatures on the third cluster were dropping and the second cluster was also getting hotter. The second cluster had been shut down just after the fourth cluster flow was stopped. Figure 4-1e shows that the second cluster was the hottest one with the third cluster obtaining high flow to force the air out of it. The fourth cluster had been reopened and also reflected the increase of flow. This series of thermographs clearly indicates that an air blockage was the problem

with flow in the third cluster, and not some mechanical blockage. This is obvious because the hot spots could be moved around the system by manual closing of flow valves and the forcing of the air out of the clusters. Also, the thermographs indicate the temperatures of the absorbing surfaces through the glass and are not just showing reflections of sunlight off the glass. The final figure (Figure 4-1f) shows that the roof array returned to a normal flow pattern after the experiment. The air had apparently been dispersed throughout the system and was not blocking any one panel. This type of indication on a thermograph would be acceptable to a technician if the system was being checked for trouble spots.

The results of the thermography studies conducted over the course of this project are the following. Thermography has been shown to be a reliable technique for determining the uniform flow patterns of large clusters of solar collectors by displaying absorbing surface temperatures pictorially. This information would allow periodic checking of solar collector systems by maintenance personnel without using temperature sensor systems installed on all the collector absorbing surfaces. Uniform flow and temperature distribution would then lead to higher efficiency from the installed collectors. Mechanical problems would be pinpointed and rapid repair accomplished in minimum time.

CHAPTER 5

DATA ANALYSIS

5.1 Introduction

This section of the report covers the analysis of the data from the past year of operation. This data is then compared to the data from the previous reports to allow yearly analysis. The collector performance is discussed and problem areas of the entire system reported. Natural gas and electricity consumption are listed for use in determining the cost of the solar energy system operation and, finally, overall analysis of performance of the total system is discussed in detail.

5.2 Past Year Performance

Throughout this past year, the performance of the solar energy systems as a whole improved steadily. This improvement was evidenced by improved efficiency in supplying the thermal demand of the house and the lack of the major problems that have been typical of the first few years. This section discusses the past year's performance with emphasis on these improvements.

As an example of the differences between the performance in the winter of 1977 and 1978, February was again chosen for analysis. Figure 5-1 shows the heating demand during February 1978 and Figure 5-2 the degree days for the same month. The total heating demand this month was 9383 MJ (8.9×10^6 Btu) of which solar energy supplied 4646 MJ (4.4×10^6 Btu) or 50 per cent. The figures in 1977 reflect

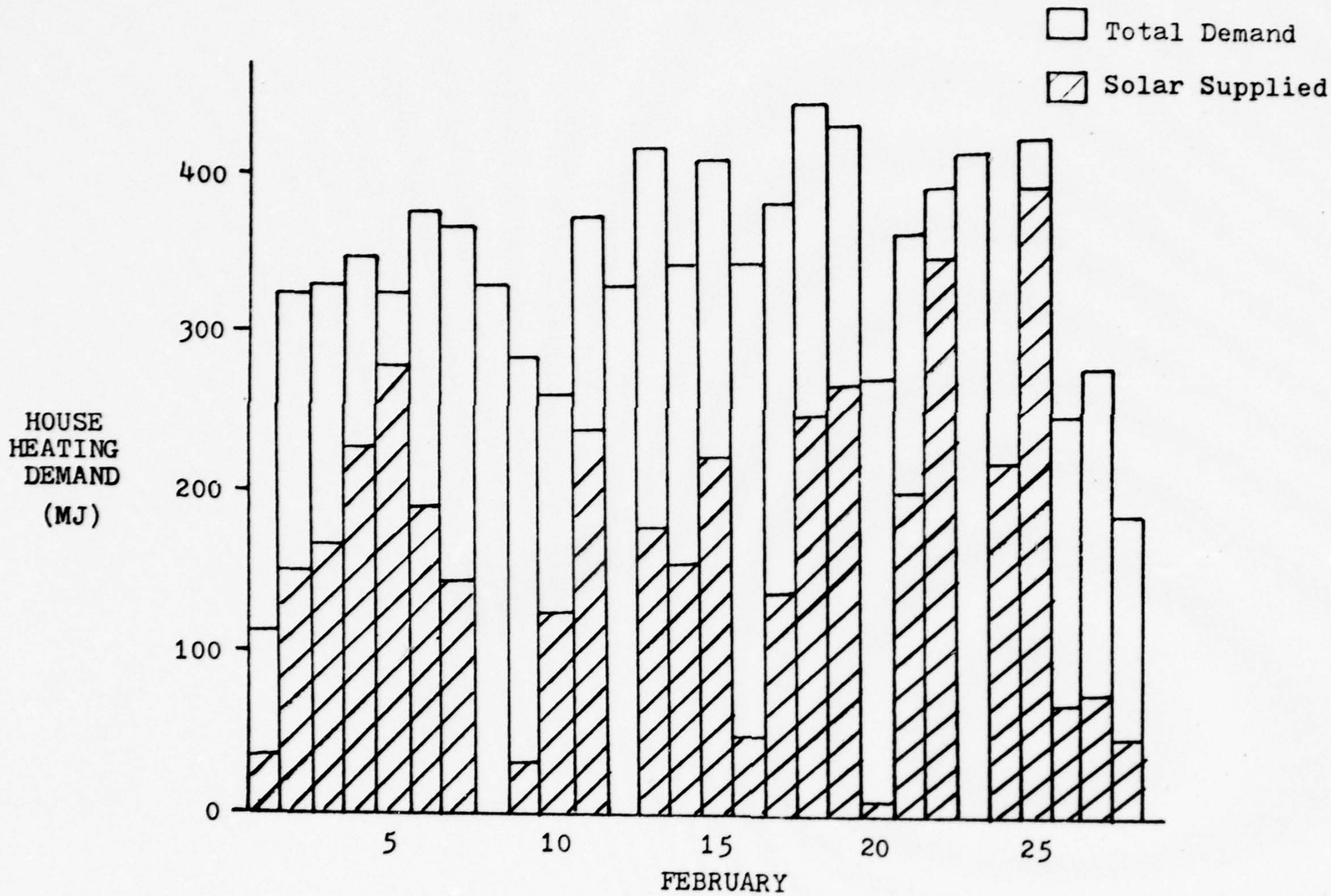

Figure 5-1. House Heating Demand [9]

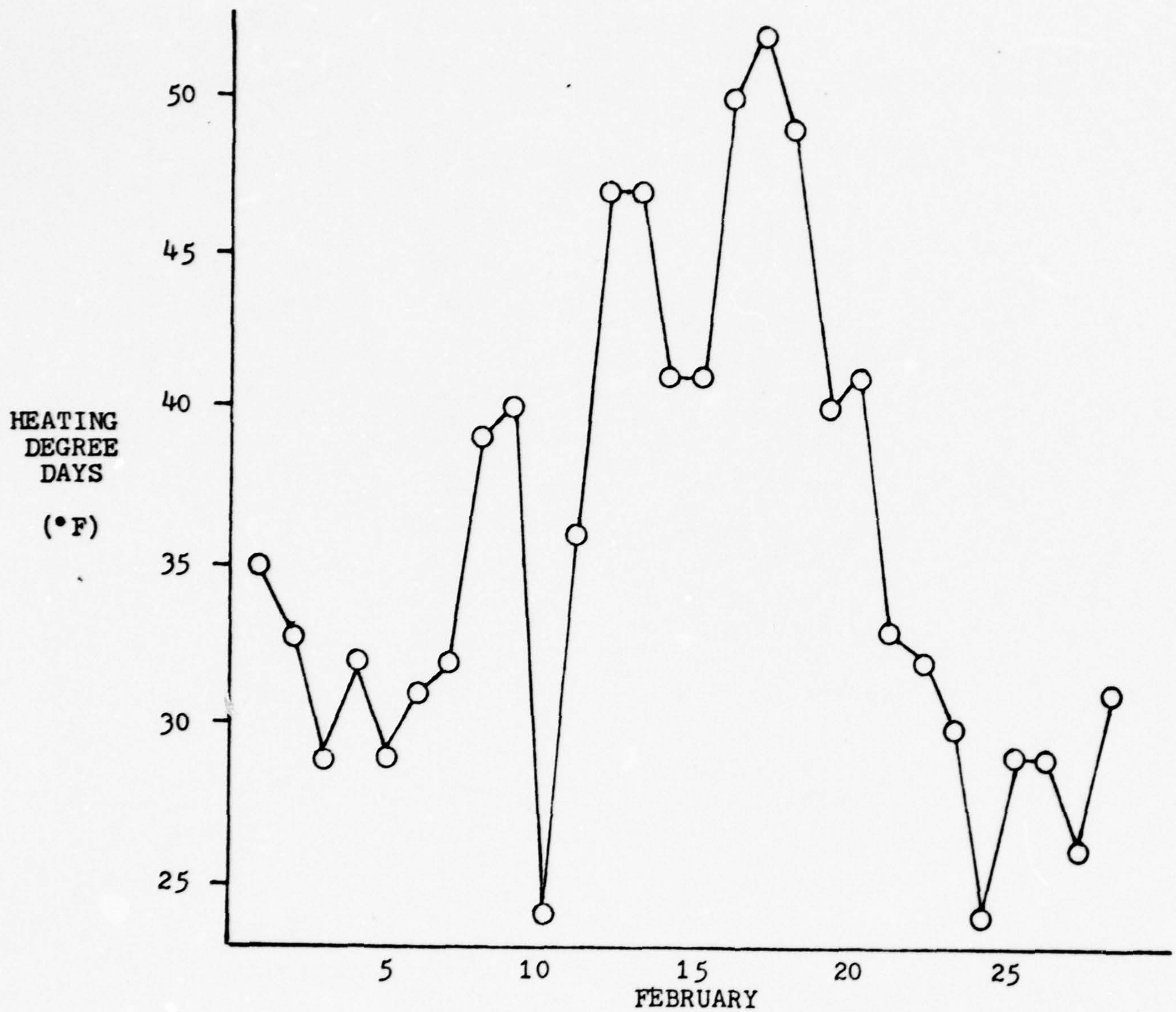

Figure 5-2. Heating Degree Days [9]

that solar energy supplied 3436 MJ (3.3×10^6 Btu) of a 7741 MJ (7.3×10^6 Btu) load, which was 44 per cent that year. This improvement cannot be accounted for by a less severe February in 1978 due to the degree days in 1978 being 1002 and the ones in 1977 were 923. Thus, the heating load in the past year increased due to lower ambient temperatures, and yet the solar energy contribution to the house heating demand increased.

Other interesting comparisons can be made between the two February figures. The house heating demand does not closely follow the degree days curve as would be expected. Most of the month, the demand stayed around 300 MJ per day with a small increase shown on the highest degree day the entire month (18 February). The Solar Test House apparently was massive and resistive enough due to the extra insulation in the walls to dampen out the severe weather effects, but at the same time not benefit from warmer days toward the end of the month. Further discussion on this point is included in Chapter 6.

The performance of solar collectors is shown in Figures 5-3 and 5-4. The first one shows the high amounts of radiation available to the arrays at their tilt of 52° when compared to horizontal during this month. The second figure reflects the higher efficiency of the ground array during almost every day. The total energy available to the two arrays was 18,776 MJ (17.8×10^6 Btu) of which 7647 MJ (7.2×10^6 Btu) was collected and sent to the storage tank. Thus, the total efficiency of the system this month was 25 per cent, which is the ratio of the available energy to the energy supplied to the house.

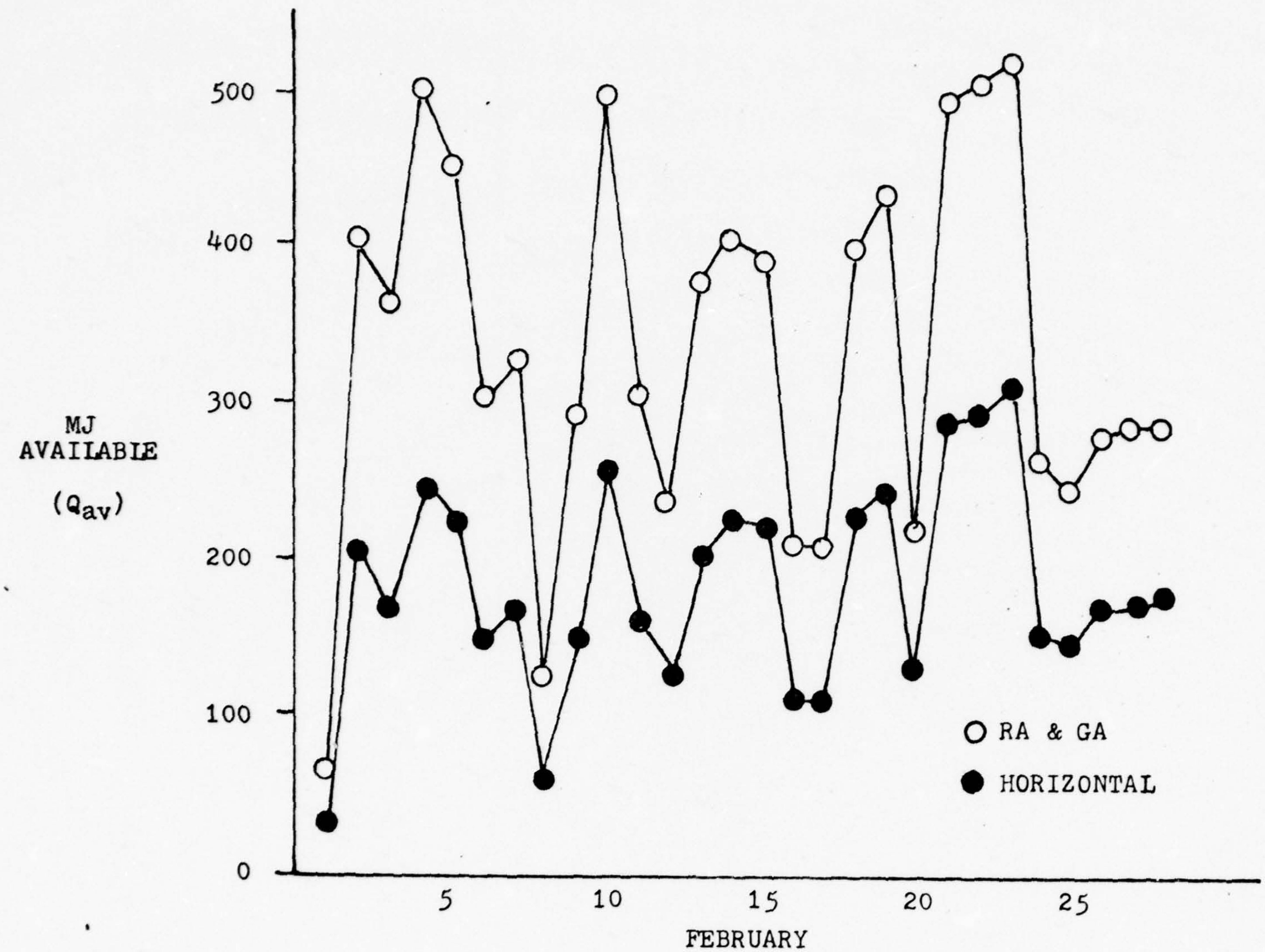

Figure 5-3. Energy Available [9]

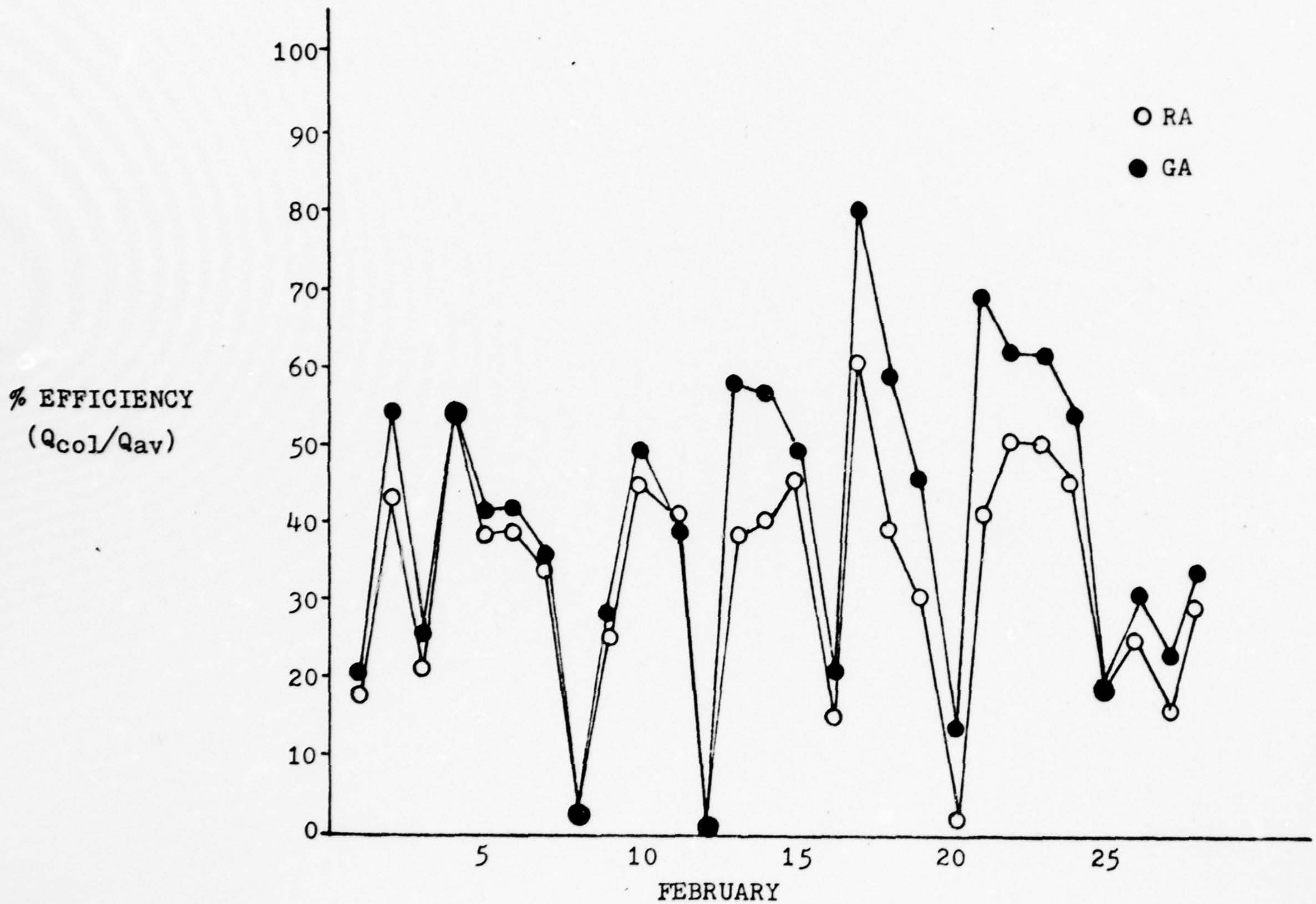

Figure 5-4. Collector Efficiency [9]

When the total year from May 1977 to April 1978 is closely examined, the following results are found. Figure 5-5 shows the monthly house heating demand for this past year and the percentage of solar provided energy to supply that demand. As can be seen in that figure, the solar energy system provided a sizable amount of energy to heat the house, including 100 per cent of heating loads in May and October. The efficiency by months is shown in Figure 5-6. The months during the summer were also 100 per cent solar, but there was little or no load during that time. The exact figures on the efficiency are listed in Table 5-1. This table illustrates the ability of the solar energy system to supply energy to satisfy some portions of large loads in the winter when the demand is the highest and the energy available the lowest. The minimum efficiency was reached in January when the per cent supplied bottomed out at 34 per cent of the demand or 3507 MJ (3.3×10^6 Btu) supplied for a thermal demand of 10,425 MJ (9.9×10^6 Btu).

During the reporting period, the degree days data showed that January was the coldest month (Figure 5-7). This data also showed that the house heating demand on Figure 5-5 followed the monthly degree days trends very closely with the highest load also in January. However, the steeply decreasing degree days curve from January to April was not matched exactly by the total load dropping as rapidly. When comparing Figure 5-5 and Figure 5-7, this can be observed by noting the different rate of decrease in the peaks during these months. Details of this observation are included in Section 6-2. It is sufficient here to say this rate difference is

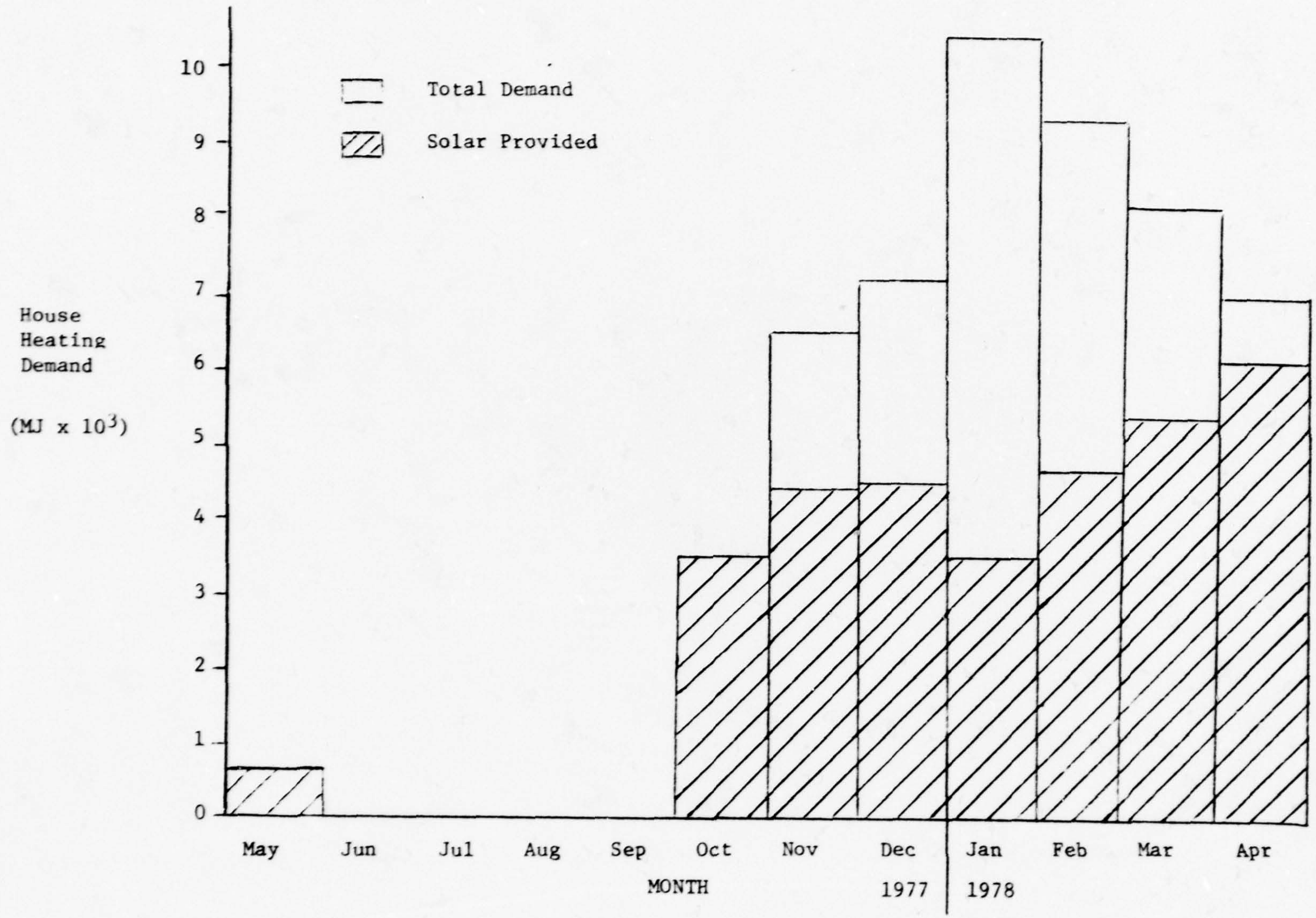

Figure 5-5. Monthly House Heating Demand

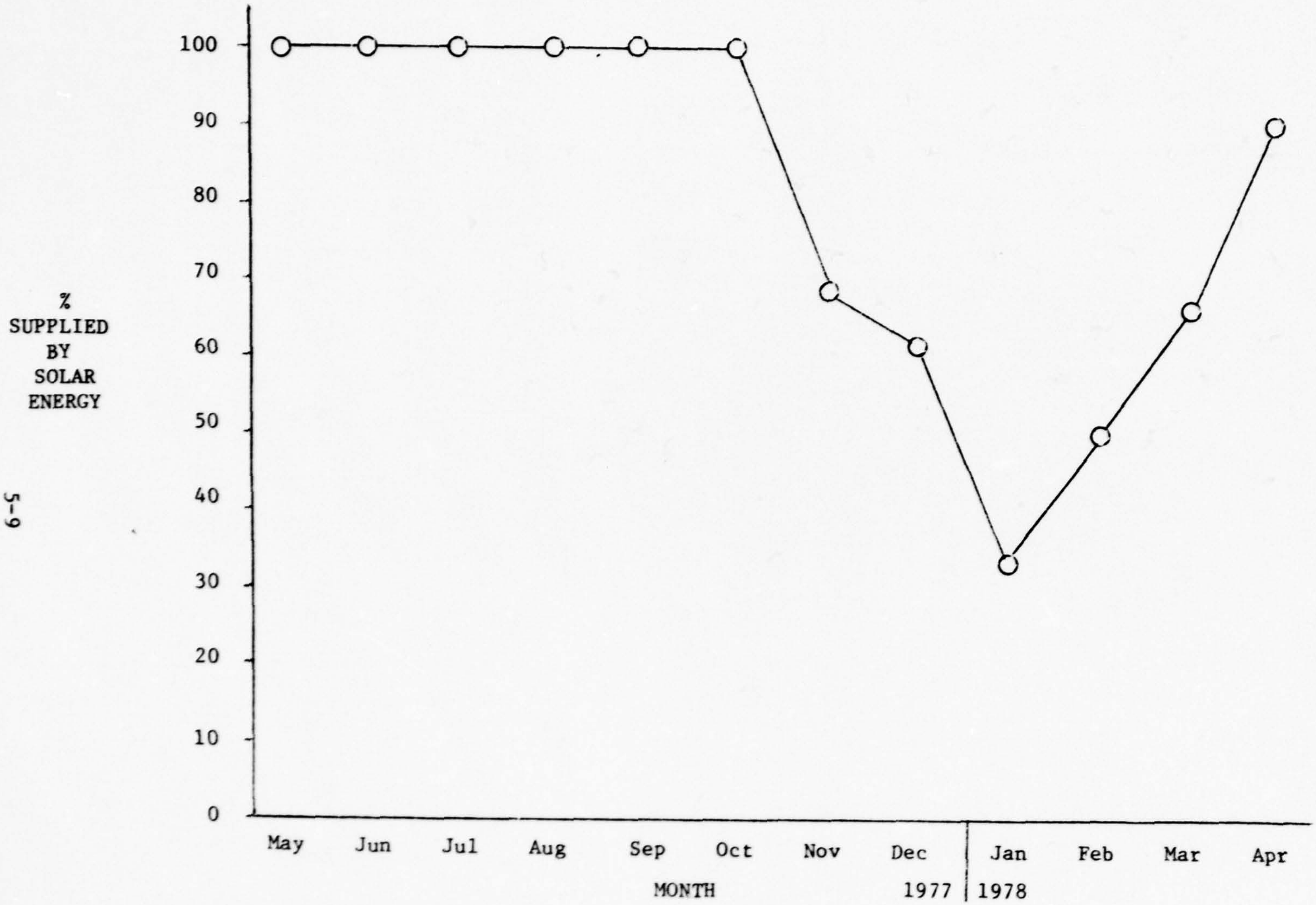

Figure 5-6. Monthly Solar Contribution

TABLE 5-1

House Heating Demand

May 1977 to April 1978

Month	Provided	%	Required
May 1977	542	100	542
June 1977	000	--	000
July 1977	000	--	000
August 1977	000	--	000
September 1977	68	100	68
October 1977	3576	100	3576
November 1977	4396	67	6525
December 1977	4427	61	7244
January 1978	3507	34	10425
February 1978	4646	50	9383
March 1978	5428	66	8201
April 1978	6086	89	6865

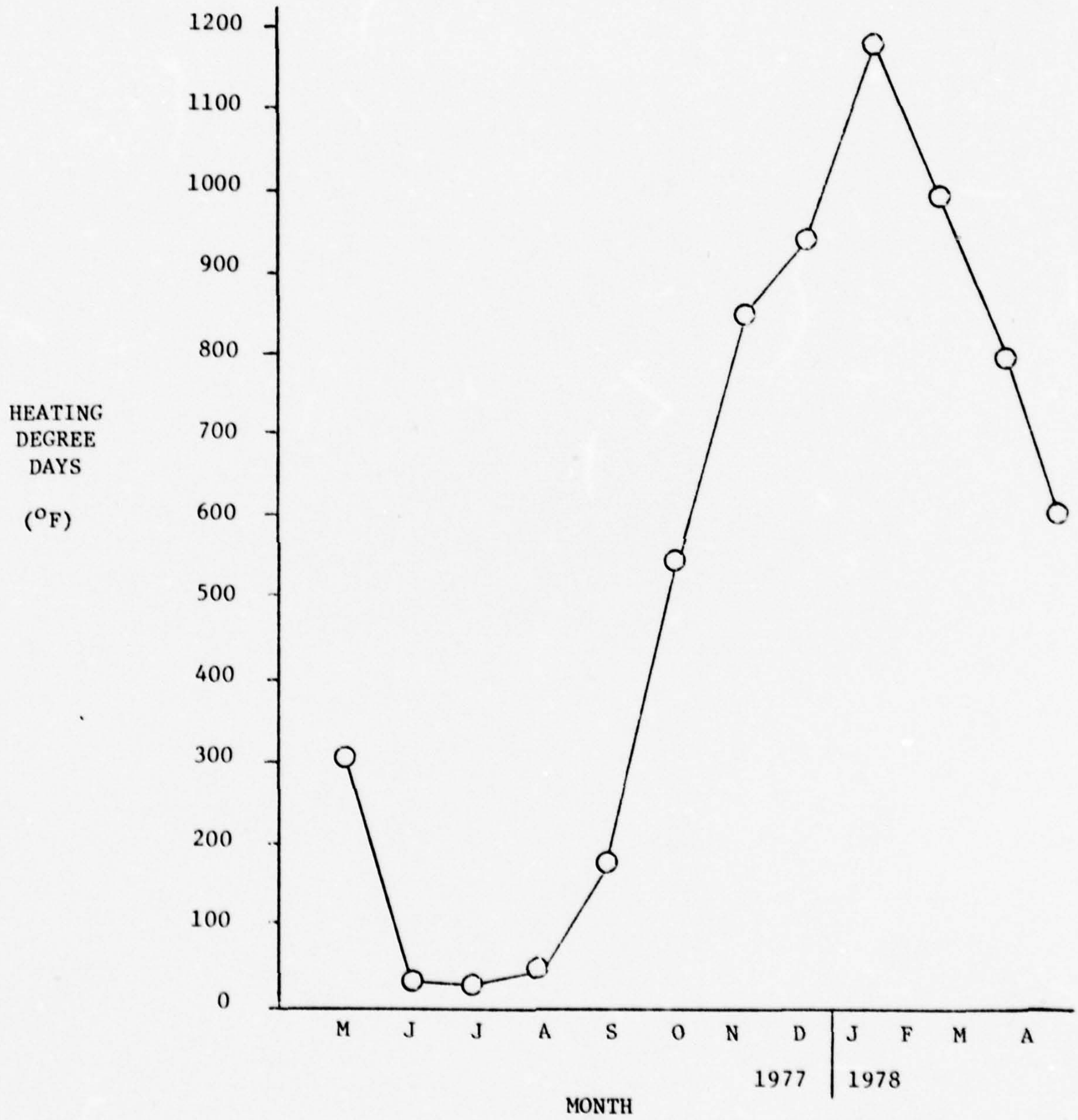

Figure 5-7. Monthly Degree Days

the effect of the house not being occupied.

Finally, Table 5-2 lists the cumulative house heating demand. This table reflects the continued improvement of the solar energy system's performance over previous periods. The totals on the table accumulate the energy required and solar provided for each year ending during that month. The final figure of 59.8 per cent is the per cent of the house heating demand supplied by solar energy from May 1977 to April 1978. This is much higher than the same period of time last year when the percentage was 48.6 per cent.

5.3 Collector Performance

The past year's collector performance was directly affected by the reduction of flow that was mentioned at the end of the second interim technical report. Figure 5-8 shows the reduced efficiency that resulted from the reduction from 30.3 liters/min (8 gpm) to 15.2 liters/min (4 gpm). After this change in operation, it became obvious that the values had to be recalibrated to accurately analyze the flow rates. The lack of accurate data in June and July is reflected by the incomplete analysis during those months. Also, April 1977 is included in Appendix B to show the analysis of that data with the new calibrations. The total amount of energy available is shown in Figure 5-9. The pyranometer was calibrated at National Oceanographic and Atmospheric Administration (NOAA) in September 1977 and was shown to be within 4 per cent of the standard. The system was shut down during July 1977 to allow drainage of the storage tank to lower the intake valves.

TABLE 5-2

CUMULATIVE

House Heating Demand
(MJ)

Month	Solar Provided	%	Total Requirements
May 1977	25433	49.0	51698
June 1977	24542	48.3	50804
July 1977	24542	48.3	50804
August 1977	24492	48.3	50754
September 1977	23760	47.5	49984
October 1977	23715	49.9	47530
November 1977	23417	54.1	43284
December 1977	25392	58.1	43688
January 1978	25785	55.7	46259
February 1978	26995	56.4	47901
March 1978	27842	56.6	49210
April 1978	31702	59.8	53051

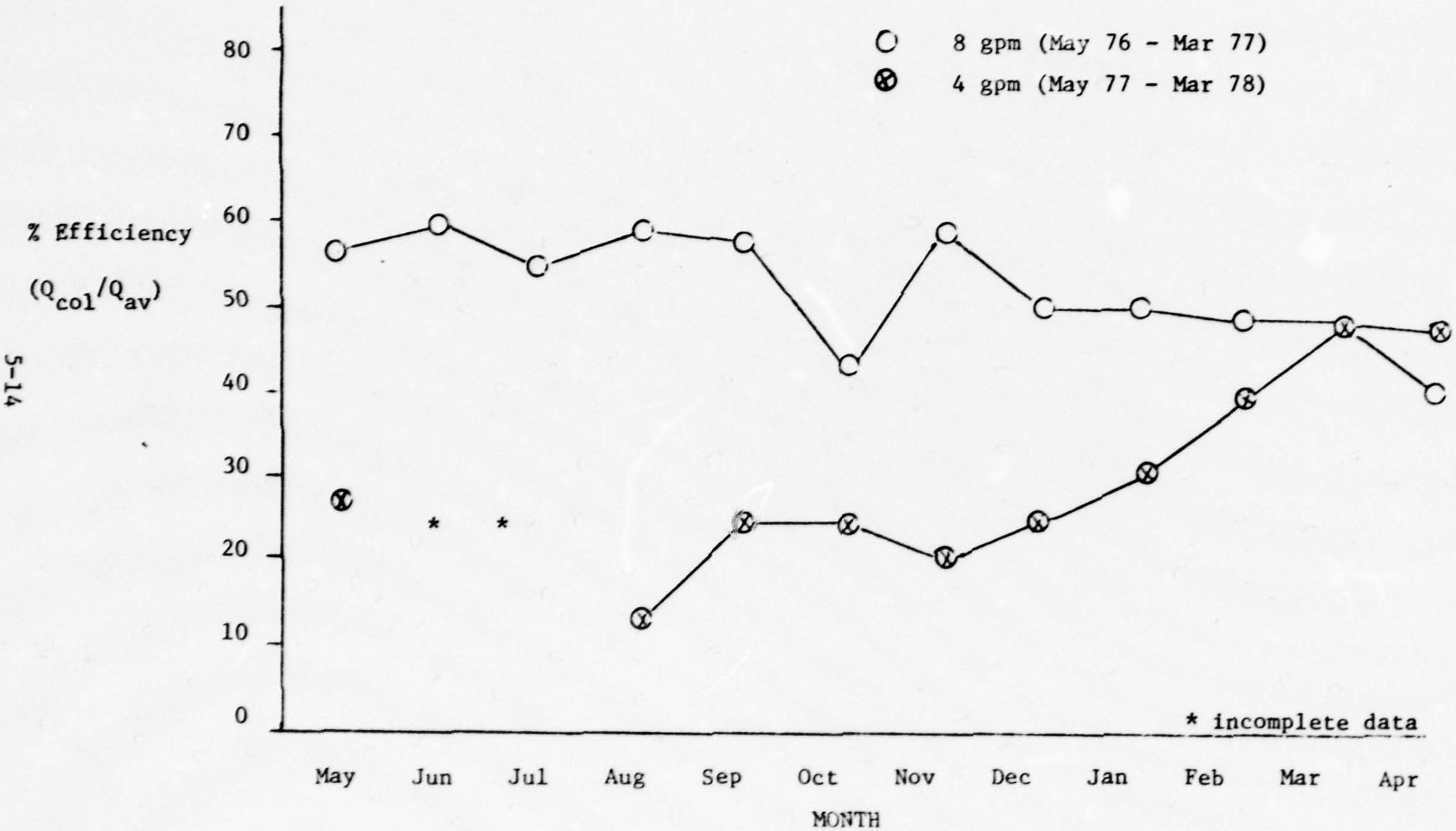

Figure 5-8. Monthly Collector Efficiency (8 gpm vs. 4 gpm)

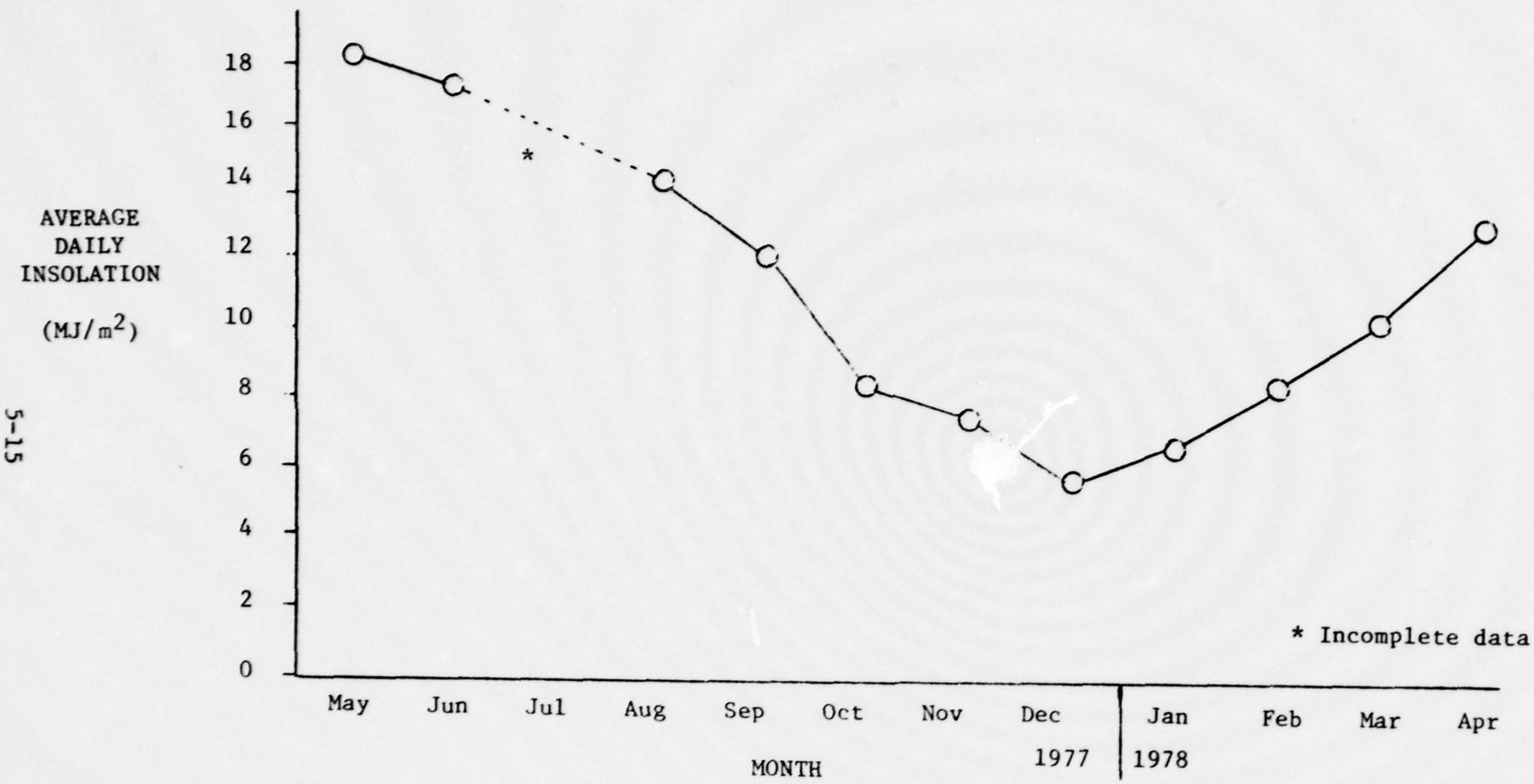

Figure 5-9. Monthly Energy Available (Horizontal)

The steady rise in efficiency shown in Figure 5-8 was examined closely. The analysis of the data during January to April shows a steady decrease in the temperature difference between the fluid in the collectors and the ambient air. This difference was 51°C (91°F) in January, 48°C (87°F) in February, 47°C (85°F) in March and 42°C (75°F) in April. These figures came from analyzing the data for good collection days during those months while the system was functioning normally from at least 10 a.m. to 2 p.m. This data analysis also led to Figure 5-10, the efficiency curve for the solar collectors during good periods of collection when there was clear weather and no snow. This data therefore supports the steady increase in efficiency at a slower flow rate during the spring.

The overall efficiency of the solar collectors during the past year was 32.9 per cent with 66,863 MJ (63.4×10^6 Btu) collected out of 203,067 MJ (192.5×10^6 Btu) available. This was compared to the efficiency during the period in the second interim technical report where the efficiency was 52.5 per cent (98,417 MJ collected from 187,588 MJ available). The sacrifice in collector efficiency was the result of the slower flow rate which allowed higher temperature water to reach the storage tank. The effects of this higher temperature water are discussed in the overall analysis in Section 5.6.

5.4 Problem Areas

This report period was characterized by fewer major problems than during the past years of operation. Generally, the solar energy system ran well with most minor difficulties involving the actual collection and distribution of the energy. The problems that did

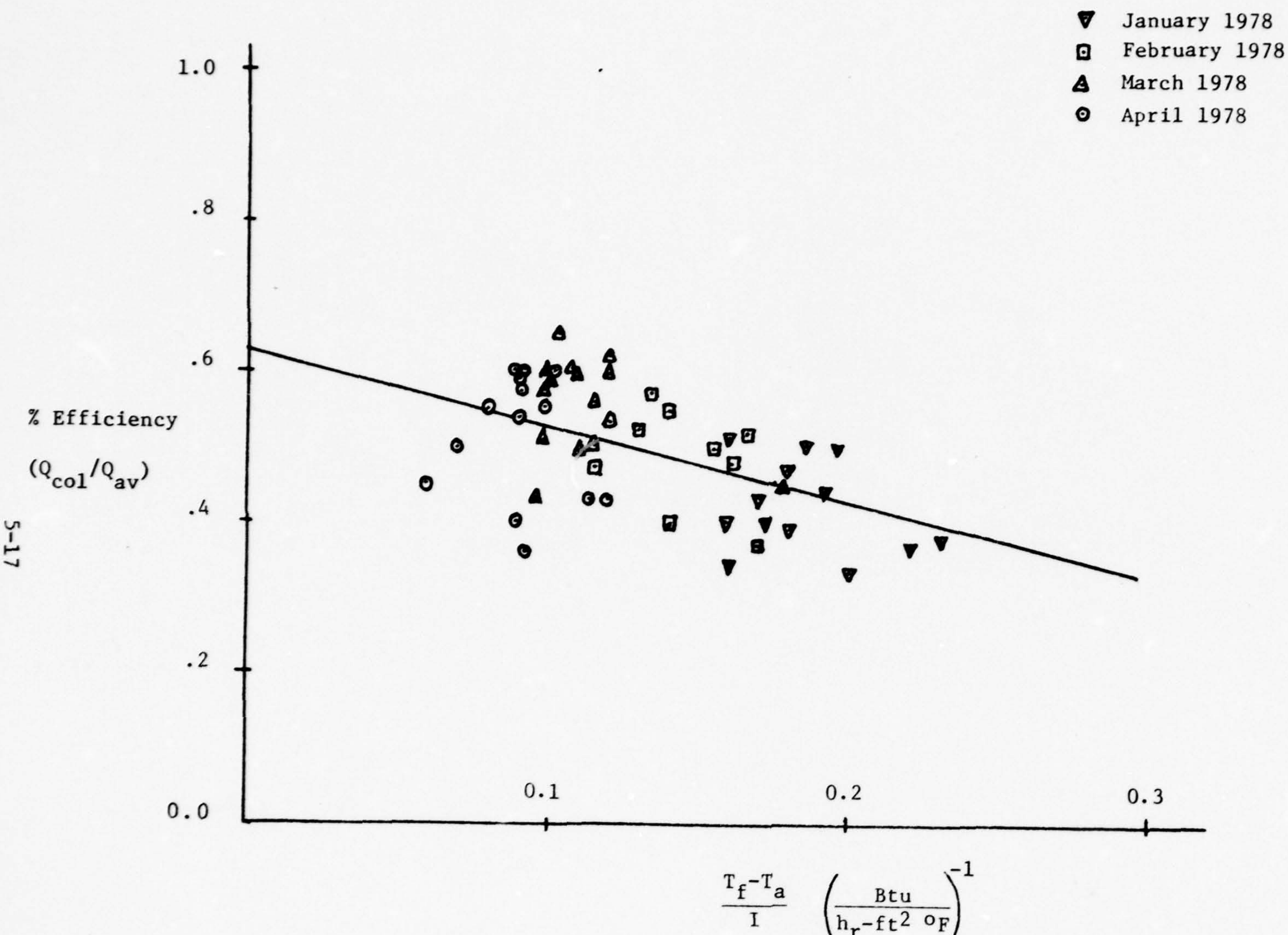

Figure 5-10. Collector Efficiency Curve

occur are discussed in this section, including air in the roof array, the make-up water system, absorbing surface deterioration, and flow rate determination.

The solution to the air in the roof array problem is discussed in Section 2.1. This bleed air system functioned relatively well, releasing the air during the day and not allowing it back in at night. The problems that developed had to do mainly with the specifications on the valves themselves. Caution had to be used to insure that the bleed air valves could stand the 420 kPa (60 psi) pressure that sometimes occurred in the roof array plumbing due to the flashing of fluid to steam in areas where air had not been completely released. Some of the valves chosen were not specified to at least this level and failed, allowing steam and fluid to escape and leak during normal operation. New valves were procured with maximum allowable pressure at 525 kPa (75 psi). These functioned very well, and completely cleared up this problem area. The bleed air system now functions perfectly when combined with the make-up water system.

The make-up water system functioned as planned after it was installed. It replaced any released air in the systems with water and maintained positive pressure at all times. However, the failure of the bleed air line on the ground array, coupled with the researchers not spotting the leak, led to the failure of a collector by freezing the diluted fluid. This problem was cleared up by the manual operation of the make-up system by the resident engineer. The occasional checking of the collector loop pressures and opening

the make-up system to allow water into the collectors proved satisfactory. Any air in the system was cleared out gradually and high efficiency was restored to the arrays. The temperatures on the absorbing surfaces would decrease over the period of a few days, and steam and air would stop coming out of the bleed air valves. A close check for leaks and a periodic check on the fluid mixture insures no reoccurrence of the dilution of the ethylene glycol down to freezing levels. The two systems, bleed air and make-up water, finally solved the air blockage problem.

The collectors themselves have performed very well since actual data gathering on performance started in December 1975. However, minor surface deterioration has occurred on some of the collector absorption surfaces. Figure 5-11 shows this deterioration on one of the roof array panels. The surface paint has peeled off in a few locations on this collector to expose the copper underneath to direct sunlight. This specific panel's surface was the worst one of all the collectors, and the vast majority of them do not have any failures at all. This minor amount of peeling was not considered a significant problem. The stains that show up in this figure are from the outgassing mentioned in the first interim technical report. The absorbing surfaces were allowed to be in the sun without fluid flow during the first days of installation and these patterns of stains on the glass resulted. Both of these problems, the surface deterioration and the glass being stained, will be investigated by cadets in the materials area through individual research projects.

Flow rate determination continued to be a problem in the data

Figure 5-11a. Absorbing Surface Deterioration
(Roof Array)

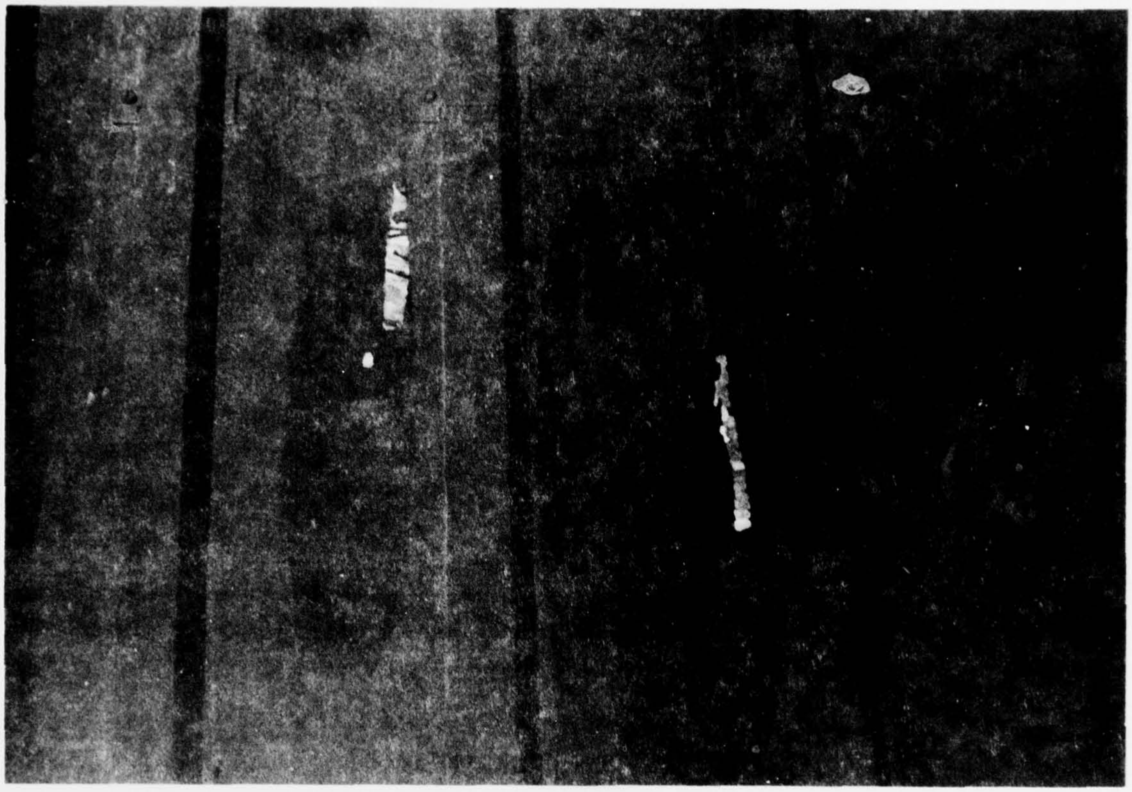

Figure 5-11b. Absorbing Surface Deterioration
(Close-up)

analysis area. The exact flow rate through each array was needed for the precise values of collected energy used in solar panel efficiency calculations. The flow rate calibration mentioned in Section 2.5 was sufficient for accuracy for the time period near the actual calibration. Mechanical slippage in the valve controller would make that calibration a monthly necessity. The flow counter circuit discussed in Chapter 3 will solve this problem by providing the actual flow rate to the analysis program through the data gathered by the microprocessor. This will be extremely critical when the new collectors are installed on the ground array. The evacuated tube collectors require very accurate control of the flow rates to operate with the desired head losses and high efficiency.

5.5 Natural Gas and Electricity Consumption

The metering of the natural gas usage and electricity consumption continued through this report period. Although correlation between the Control House (CH) and the Solar Test House (STH) continued to be very difficult due to family size and activity differences, the figures for each structure can still be used for indications of the effectiveness of their solar energy system and energy conservation. Table 5-3 shows the savings realized by the use of solar energy for the STH thermal loads. This table is a summary of the information in Appendix C. These figures show an increase in the natural gas savings of this past year when compared with the same time frame in the previous report. The total savings of 52 per cent of the natural gas usage is significant since the previous period's

savings were only 36 per cent. The figure on domestic hot water (DHW) savings reflects the solar energy contribution to that load by saving 46 per cent of the natural gas. This number is still the only means of determining the effectiveness of the solar energy system until the hot water preheat measurement system is installed.

NATURAL GAS SAVINGS (ft^3)

	Total	HHD	DHW
CH	202,190	145,630	49,840
STH	97,740	73,340	27,130*
Savings	104,450	72,290	22,710
%	52	50	46

*Includes 800 ft^3 added for February to April 1978

Table 5-3. Natural Gas Savings

Electricity consumption of the STH is also listed in Appendix C by totals measured for each of the major components: the fan and the four pumps. The total consumption of electricity to power the solar energy systems during this last year was 3942.6 KWH. Since the fan would have been used to provide the house heating demand (HHD) even with all natural gas, the consumption without it was 2569.3 KWH. The energy delivered by the solar energy system during this time was 50,756 MJ including the figure of 19,054 MJ (18×10^6 Btu) for 22,710 cubic feet of natural gas for DHW. The ratio of MJ/KWH was 19.75 and 18,720 for Btu/KWH.

5.6 Overall Analysis

This section of the report will examine the total performance data for the solar energy system throughout the entire operation since start up and data gathering began. The system's efficiency for supplying the heating demand of the Solar Test House is shown in Figure 5-12. This figure shows the gross amounts of solar energy provided toward satisfying the thermal demand. As the system operation became more efficient and the parameters more closely aligned with design values, the solar energy system supplied more and more energy to the house. Figure 5-13 illustrates this overall increase in efficiency. The earliest months of operation were plagued with start-up problems and the latest months reflect the changes in operation that allowed the system efficiency to increase. Some of these changes were the storage tank volume reduction, slowing of the flow rate through the solar collectors and the use of urea foam in the structure to decrease the load.

Figure 5-14 shows the overall degree days data for the period of the project. This illustrates that the two winters totally covered by this time were not extremely different in severity. Figure 5-15 shows the insolation available to the arrays and illustrates that the two summers had slightly different peaks in radiation rates. These two figures reflect the variations that occurred due to weather phenomena affecting temperatures and insolation. The variations between them are illustrations of actual data as it occurred and how it can be different from year to year. Designers must remember the averages listed in most sources can be misleading

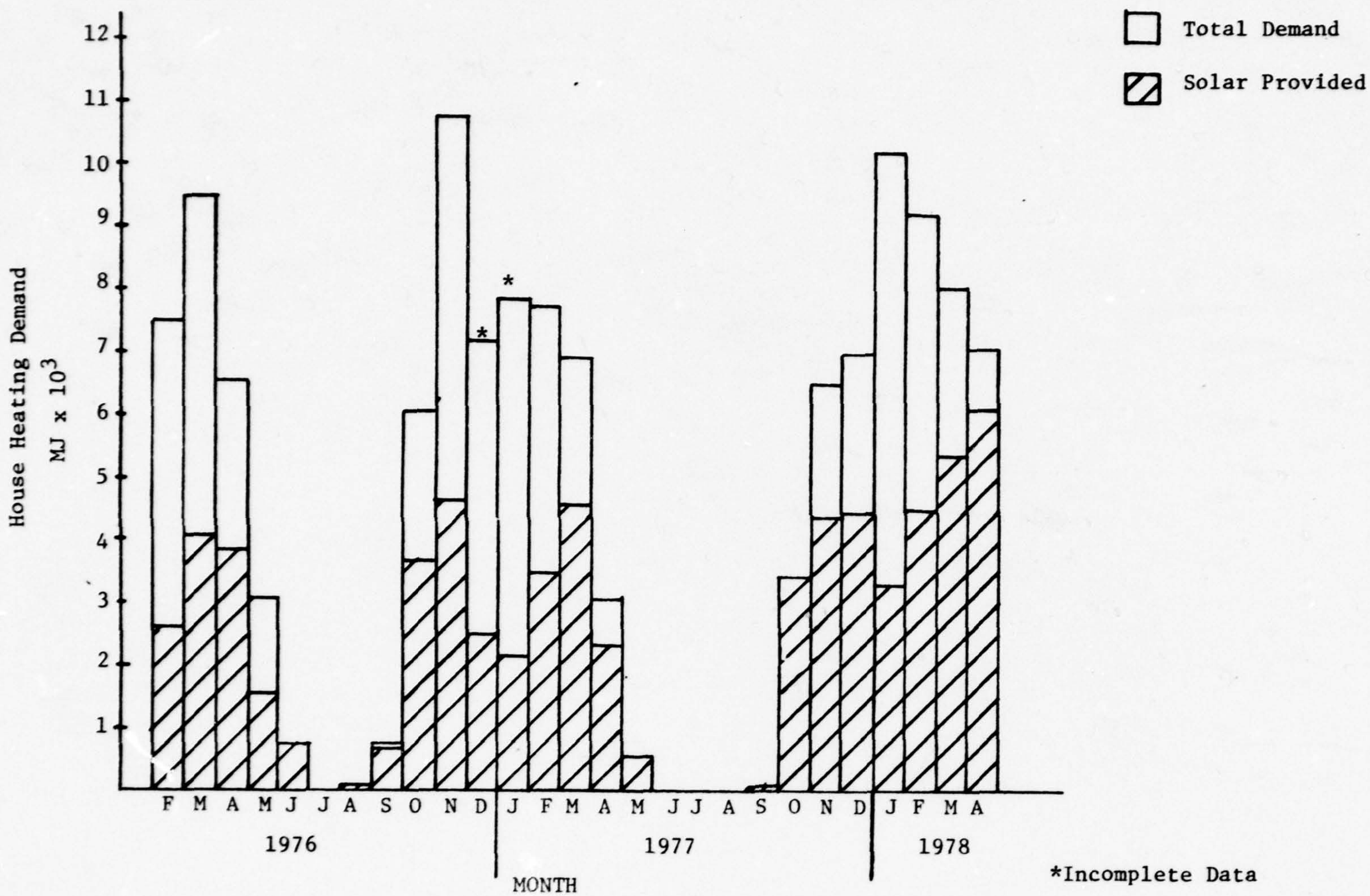

Figure 5-12. Total House Heating Demand

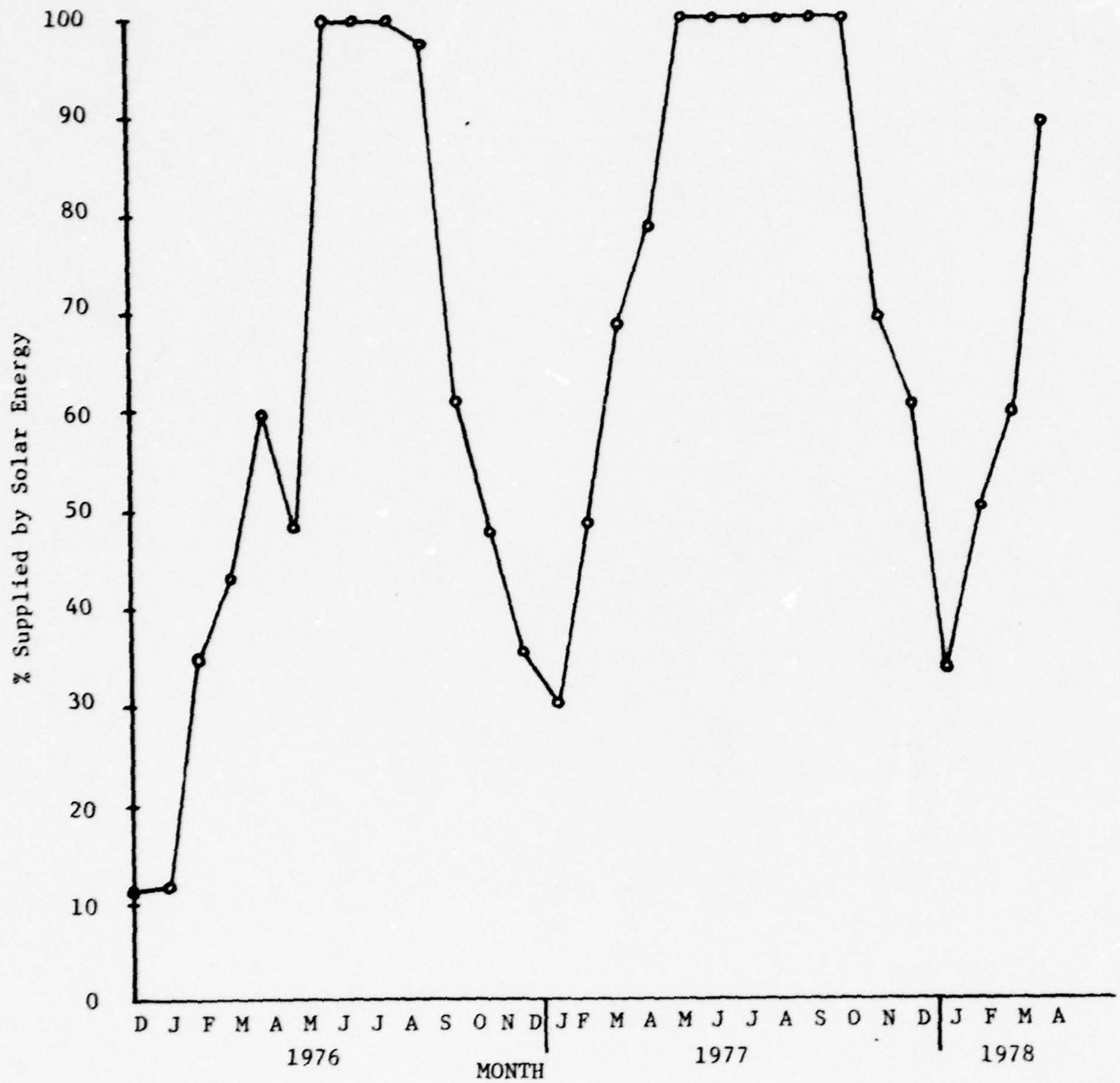

Figure 5-13. Total Solar Contribution

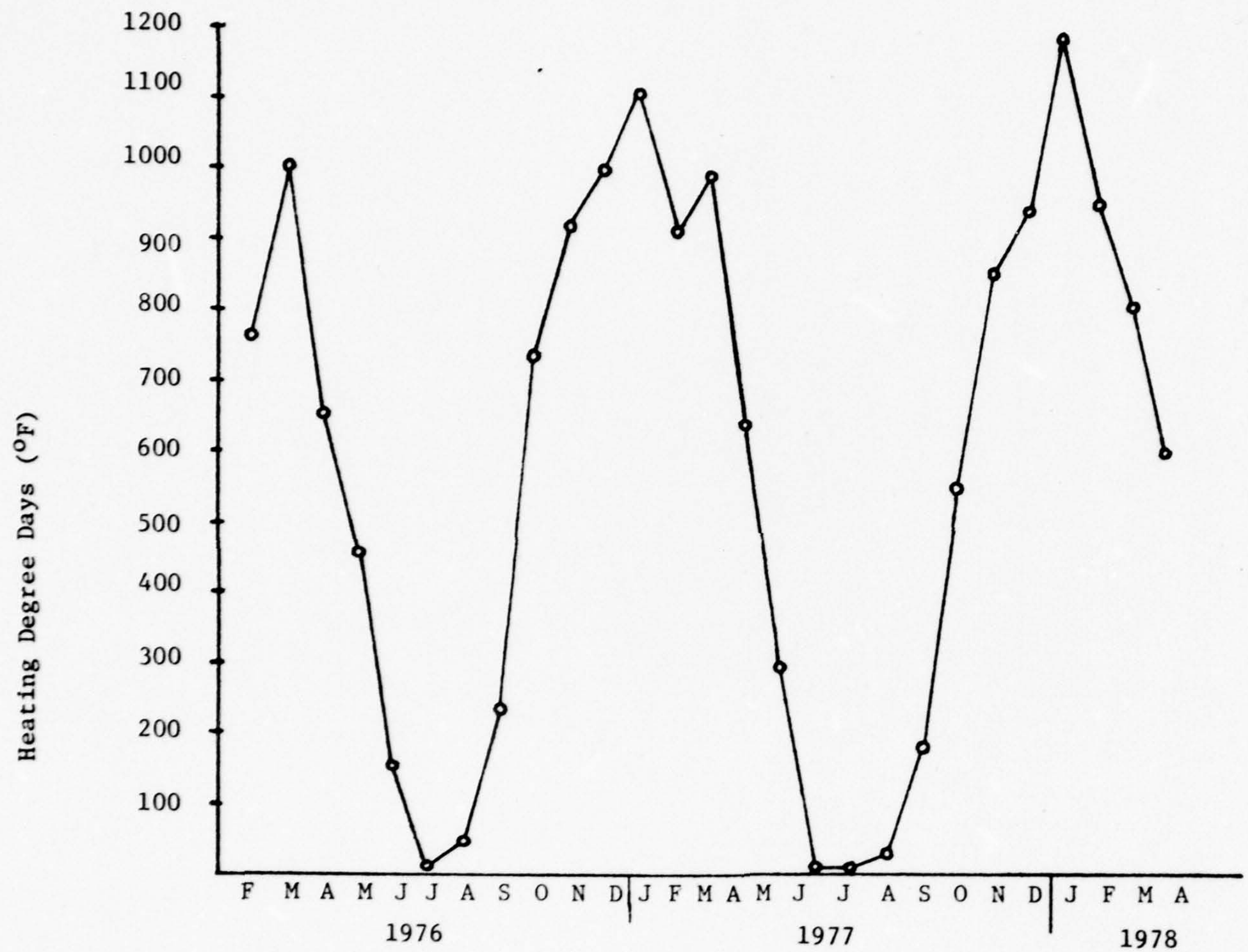

Figure 5-14. Total Heating Degree Days

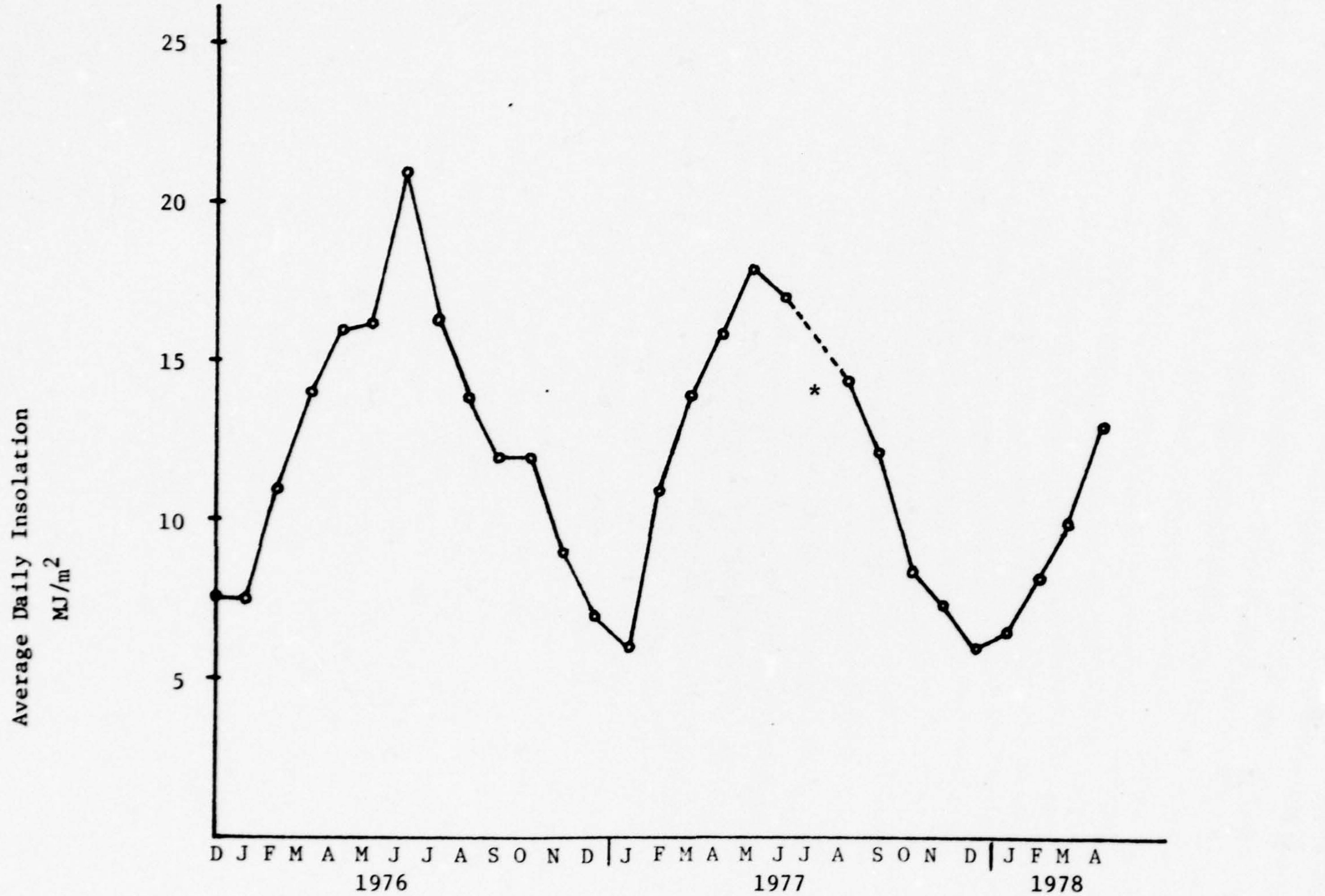

Figure 5-15. Total Energy Available (Horizontal)

when extreme years occur or exact predicted performance is expected during each period of operation.

Overall, the following data are the results of the comparison between the two years, May 1976 to April 1977 (1977) and May 1977 to April 1978 (1978). The degree days decreased 9 per cent from the first year to the second with the figures being 7148 in 1977 and 6480 in 1978. This was reflected in a slight decrease in the house heating demand over the same period. The heating load in 1977 was 53,256 MJ (50.5×10^6 Btu) and in 1978 was 53,051 MJ (50.3×10^6 Btu), which was a decrease of 2 per cent. The explanation why this decrease was not greater is discussed in detail in the energy conservation section. For now, the lack of decrease is thought to be a reflection of the effects of no occupants in the house during the winter of 1978.

Solar energy provided 48.6 per cent of the house heating demand in 1977, 26,353 MJ (25×10^6 Btu) while in 1978 it provided 59.8 per cent, 31,702 MJ (30×10^6 Btu). This overall increase of 20 per cent more energy provided from one year to the next was due to a number of factors. First, the collector flow rate was slowed to a lesser value during 1978. This led directly to a decrease in collector efficiency, but an increase in the temperature of the hot water coming back from the collectors into the storage tank. Secondly, the storage tank mass had been lowered to a level which allowed the mass to react more quickly to the higher temperature, slower flowing solar collector fluid. This effect then allowed the tank to rise to a higher, more usable temperature level for use in the house

heating cycle. The storage tank did not have the capability to store for as long a period, but was usable more often. Thirdly, the urea foam and other energy conservation did decrease the thermal load of the structure at first and allowed the solar energy system to attack a smaller problem. Figure 5-12 shows this lowered load in the two Octobers and Novembers. Continued performance improvement due to this action stopped when the occupants departed.

If the efficiency of the total system is examined in detail, the following results. The ratio of the energy available to the energy actually delivered to the house was 14 per cent in 1977 and 16 per cent in 1978. These percentages in just the heating seasons were 19 per cent in 1977 and 25 per cent in 1978. Both sets of figures show the improvement of overall performance obtained by the variation of the previously mentioned parameters. Specifically, collector performance was sacrificed for overall system performance. The slower flow through the collectors lowered their efficiency, the lowered tank mass decreased storage capability, but the energy supplied to the house increased. Since the problem is one of keeping the structure warm, those sacrifices were considered worthwhile. At present, it is not known if the optimum has been reached. If some slowing of the flow rate is good, could there be an even lower rate that's better? Storage tank mass could be lowered further to investigate the effects of the tank mass parameter. These two steps will be possible during the next research period with the following problems. Flow rate must be determined by actual measurement and not valve calibration. The flow counter will

permit this determination and overcome the hysterisis effects of the valve position during operation. However, the storage tank may be heated to a much higher level during testing and operation of the new, evacuated tube collectors. This will cause problems in determining the effect of the flow rate reduction during the next winter due to the possible elevation of the total system's fluid temperature. The storage tank heat exchangers are currently in position at the bottom of the tank. Any further reduction of the water level would expose them to the air. Thus, without new plumbing of the heat exchangers, the present level is as low as the water can be without very poor heat exchange occurring.

CHAPTER 6

ENERGY CONSERVATION

6.1 Introduction

Since the outset of the solar energy project, the Solar Test House heating load has been closely monitored and attempts were made to reduce it. The second interim technical report listed the major efforts at reduction, including the use of urea foam. This chapter will cover the continued results of those energy conservation techniques and the apparent effects of the lack of occupants during 1978.

6.2 Reduction Due to Conservation Techniques

The last energy conservation technique applied to the Solar Test House was the installation of interior storm windows on all the windows of the structure. This triple glazing would cut down the conductive losses through the windows by creating another dead air space of insulation between the outside and inside air. Infiltration losses would also be decreased due to the more tightly sealed windows resulting from the close fit of this extra layer of glass and frame. Some extra solar gain would also occur by the reduction of the re-radiation of the energy back through the glass after the interior had absorbed it and emitted the radiation. Appendix D shows the expected difference that the third layer of glass could make. The reduction in expected load would be 13 per cent.

Table 6-1 lists the heating demand for the Solar Test House as it actually occurred from October 1976 to April 1978 for comparison.

TABLE 6-1

HEATING DEMAND
(Natural Gas and Solar Energy)

Month	DD °F	CH MJ	STH MJ	STH/CH	STH/DD
Oct 76	698	9,279	6,056	0.61	8.68
Nov	906	15,169	10,771	0.71	11.89
Dec	1054	21,537	7,029*	0.33*	6.67
Jan 77	1125	25,103	7,854*	0.31*	6.98
Feb	921	21,126	7,741	0.37	8.40
Mar	986	20,371	6,892	0.34	6.99
Apr	603	17,132	3,024	0.18	5.01
May	297	1,737	542	0.31	1.82
Jun	20	0	0	--	--
Jul	16	0	0	--	--
Aug	56	0	0	--	--
Sep	173	655	68	0.10	0.39
Oct	546	5,521	3,576	0.64	6.55
Nov	846	12,493	6,525	0.52	7.71
Dec	950	18,626	7,244	0.39	7.63
Jan 78	1191	22,385	10,425	0.47	8.75
Feb	1002	19,348	9,383	0.40	18.12
Mar	801	18,005	8,201	0.46	10.24
Apr	582	10,102	6,865	0.68	11.80

* Partial Data

The heating demand supplied by either natural gas or solar energy continued to show a reduction from past loads through the fall of 1977. This is evidenced by the lower ratio of heating load to degree days between 1976 and 1977. The data for the months of December 1976 and January 1977 were characterized by problems with the transfer programs and were considered to be partial figures. Therefore, for the early part of the heating season this last year, continued energy conservation resulted from the techniques employed at the house. The differences in the magnitudes of the demands of the Control House and the Solar Test House once again illustrate the poor correlation between these two structures.

6.3 Increases with Lack of Occupants

The continuation of the reduction in heating demand of the structure stopped in February 1978. This can be seen by examination of Table 6-1. The ratio of heating load to degree days increased dramatically that month and remained higher than the previous year's figures through March and April 1978. The only significant change that occurred during this period was the lack of occupants in the Solar Test House. The resident engineer and his family departed PCS in January 1978. From then on, the heating demand apparently increased without a large increase in degree days. That ratio went up, and so did the ratio between the Control House and the Solar Test House loads. Correlation between these two demands is not good, but the fact that the ratio changed in parallel with the apparent increase in Solar Test House heating

load with respect to degree days leads to confidence in the figures in general.

Some possible reasons why a house load could increase without occupants follows. The Solar Test House is so well insulated that infiltration has been cut down to insignificant levels far below the usual figure of 20 per cent to 30 per cent of the heating load. The urea foam in the walls and especially the addition of vestibules would account for that phenomena. The occupants leaving eliminated the usual gains from cooking, lights, body heat, cleaning, and other functions of a household. There is less mass, such as furniture, in the structure to hold energy and less insulation on the floors due to no rugs. Solar gains through the windows were reduced due to the blinds being fully closed with no occupants in the house. This effect is especially important during the winter months when the sun is low in the sky. From all these reasons, and from the figures on heating demand, it appears that a well insulated house experiences an increase in heating load with the lack of occupants when the only measurements being made are those of the natural gas and solar energy contributions. The input from other sources of thermal energy were not measured during this time. These figures, therefore, must be viewed with the consideration of the possible contributions to meeting the heating demand of the natural gas used for cooking and the electricity consumed in the house.

CHAPTER 7

DESIGN PARAMETER ANALYSIS

7.1 Introduction

When the solar energy research project began at the USAF Academy in 1975, design parameters were usually found in very technical papers or reports on research. Few, if any, existed within easy reach of a typical engineer just starting out in this design process. A few rules-of-thumb [5] existed within the solar design field, but they, too, had to be tracked down by obtaining reports on past work. Today, the area of design parameters has expanded greatly, almost to the point of having so much information that an engineer is hard pressed to separate proven ones from hopeful ones. This section of the report will list the various design parameters that were used originally in the design of the Solar Test House and the verification or modifications of these as the project progressed. The "f" chart method [6] will be discussed in light of how closely this technique of predicting performance came to the actual figures for the Solar Test House.

7.2 Collector Area

Due to the high cost of this component, collector area is usually the first consideration examined in designing a solar energy system. Collectors vary greatly in their efficiency, absorption surface materials, glass layers and even general construction. However, some guidance does exist on first estimates of the required area of panels.

A rough estimate can be made of the area of the collectors if the following parameter is used. The area of the structure to be heated is determined and 25 per cent to 40 per cent of that area is required for the solar collecter area. It is estimated this will provide between 40 per cent to 70 per cent of the heating demand in an active system.

The area of the Solar Test House to be heated is 176.5 m^2 (1900 ft^2). Using the recommended factor for collector area yields a range of 44.1 m^2 (475 ft^2) to 70.6 m^2 (760 ft^2). The overall efficiency for heating the house with solar energy from Section 5.2 was 60 per cent. This figure falls into the efficiency range mentioned for the estimated area of collectors since the area used on the Solar Test House was 50.7 m^2 (546 ft^2). Since there is a wide spread in the possible performance of the various collectors and the loads of different houses, this design parameter appears sufficient for use as a first estimate collector area.

7.3 Collector Tilt

Once the area of the collectors has been estimated, the tilt or slope with respect to the horizontal must be determined. Important structural and architectural considerations depend greatly on this parameter. The additional load onto a roof structure, or the placement of a ground array both require the angle at which the collectors will be placed in order to design the structural members. In a retrofit application, the tilt determines whether or not the collectors can be placed on the roof without additional strengthening of the existing trusses.

Many sources list guidance on determining the tilt of the solar energy collector. The angle depends greatly on the application intended. Most rules recommend the slope to be latitude plus 10^{o} to 15^{o} for heating applications, latitude for domestic hot water or other all year applications, and latitude minus 10^{o} to 15^{o} for cooling.

The angle set on the roof array is 52^{o}. This falls into the range of latitude (39^{o}N) plus 10^{o} to 15^{o} (49^{o} to 54^{o}). Although structural considerations played a large role in this angle's determination, it was set at the angle for heating or winter applications.

The ground array tilt was constructed at 45^{o}, with saddles and hinges to allow changes to 52^{o} and 60^{o}. These various angles allowed research into the effects of tilt in collector efficiency. As has been discussed in the second interim technical report and in Section 2.3 of this report, the various angles were better than 52^{o} for collecting solar energy at different times of the year. Not surprising was the discovery of 60^{o} being the best angle for winter collection from 3 November to 20 February and 45^{o} being better for summer collection. The overall compromise angle of 52^{o} for all-year collection was shown to be just that, a compromise that functions best from 3 October to 3 March [3]. Since overall collector efficiency during this research was 33 per cent, the tilts of the ground array and the setting of the roof array at 52^{o} proved reasonable. Most construction will not allow variation of collector angles. Therefore, the slope of latitude plus 10^{o} to

15^o is considered a good angle for solar collectors for heating applications in the winter and domestic hot water in the summer as well.

7.4 Storage Tank Volume

Another large item in the design of a solar energy system is the storage tank. This tank can be considered the heart of the system because it ties together the solar energy gained by the collectors to the thermal energy required by the load. If the storage tank is too large, most of the collected energy is used to raise its temperature a few degrees. This raise may not be to a sufficiently high level to be usable in a direct heating system such as the one in the Solar Test House. If the storage tank is too small, there is not enough mass to sufficiently store the energy to last overnight or during low collection periods.

A recommended volume for a typical solar energy storage tank is 60 to 100 liters/m^2 (1.5 to 2.5 gallons/ft^2) of collector area. With 50.7 m^2 of collectors in this system, the volume range would be 3042 to 5070 liters (819 to 1365 gallons) of water.

The initial volume of the storage tank was approximately 9464 liters (2500 gallons). As was discussed in the second interim technical report, this volume was first reduced to 6814 liters (1800 gallons) due to a lack of high enough water temperatures in the tank for use in heating the house. A further reduction to 5400 liters (1400 gallons) was discussed in Section 2.4. The immediate effects of both of these reductions in the storage tank mass was the increase in the water temperatures to allow longer usage of the

collected energy. However, the storage capability was reduced by the smaller mass, allowing storage to last a maximum of two days in March and April 1978. The present volume is still slightly more than the recommended range. After observing the effects of this smaller mass on the overall system efficiency for heating the structure, no further reductions are planned. This design volume is sufficient to allow usage of the stored energy at an increased rate and yet store energy for long periods of no collection. Also, once the storage tank was run down to a low temperature, this volume would allow relatively rapid return to a usable level during the next collection period.

7.5 Storage Tank Heat Exchangers

Except for other than normal design procedures for heat exchangers, no specific guidance was available to the designers on the size of the ones used in the storage tank. After the first year of operation, it was noted that the possibility existed for improving the performance of the collection system by a more efficient heat exchange between the collector fluid loop and the storage tank water. This led to the addition of the third heat exchanger in the ground array loop.

As was discussed in collector efficiency in Section 5.3, the third heat exchanger did improve the efficiency of the ground array collection of solar energy. This extra exchanger allowed that system to work at a relatively cooler temperature than the roof array. With the fluid at a lower temperature, the ground array collector efficiency was slightly higher than the roof array with both systems

at the same tilt. It is sufficient to say that the heat exchangers should be designed for the best possible heat transfer in the storage tank without any large pressure drops and subsequent pumping requirements.

7.6 Collector Flow Rate

After the panel type, size, and plumbing configuration is designed, and the heat exchangers and connecting pipes sized, the flow rate for the system must be determined for proper pump selection. This flow rate will directly affect the efficiency of the solar energy collectors due to the fluid's capacity to carry away the energy in the absorbing surface. If the flow rate is too high, the collectors function at a high efficiency due to a rapid heat transfer from the tubes to the cool fluid. This lowers the absorbing surface temperature and increases panel efficiency. However, the fluid is not as warm as desired and does not heat the storage tank to a usable level. If the flow rate is too low, the fluid is heated to a very high temperature and the absorbing surface is allowed to warm up considerably. The higher the absorbing surface temperature, the greater the driving force transferring energy across the glass into the atmosphere and the higher the collector losses in general.

The rule of thumb for flow rates usually recommends 0.81 $l/min/m^2$ ($0.02\ gpm/ft^2$) of collector area for water systems. As mentioned in the second interim technical report, the initial flow rate for this system was at a much higher rate of 2.39 $l/min/m^2$

($0.059 \ gpm/ft^2$) which is almost three times as high as recommended. Information available at the time of the original design seemed to indicate this high flow rate. After the initial thermography studies, this rate was supposedly cut in half. After the correlation of valve positions to flow rate mentioned in Section 2.5, the final flow rate at full open was set approximately at 15 l/min (4 gpm) which equals the ratio of $0.60 \ l/min/m^2$ ($0.015 \ gpm/ft^2$). This reduced flow rate had the immediate predicted effect upon the efficiency. The panels began to run at lower efficiency of collection as the fluid was allowed to heat up to a higher temperature. However, overall system efficiency improved as the storage tank water temperature rose more often into a usable range for heating the house. This trend continued through the last winter as the arrays struggled at efficiencies near 20 per cent but the system supplied larger than ever amounts of thermal energy to the Solar Test House. Thus, the parameter for the flow rate is a valid one for overall system efficiency. The most important task is to heat the house and domestic hot water. A sacrifice in collector efficiency toward this goal is well worthwhile.

7.7 Control Temperatures

The importance of properly chosen control temperatures for the various solar energy systems cannot be overstressed. Control temperatures dictate the performance of the collection system by determining when the valve should be opened and the pump turned on. The temperature difference between the inlet and outlet of the collector

controls the flow rate into the panels. The return temperature from the collectors, when compared to the storage tank, determines the shutdown rate of the collection system. Finally, the lowest storage tank temperature allowed for solar energy usage in the house directly affects the overall efficiency of the total system when supplying thermal energy to the structure.

The initial selection of a difference of temperatures between the absorption surface of the collectors and the storage tank was 11°C (20°F). This temperature difference was sufficient to allow the valves to open to their first positions and turn on the pump without losing energy during the first winter of operation. If a simple, two-position valve arrangement had been used, this start up setting would have proven acceptable in all cases except very marginal days.

The temperature difference chosen for the gain across the panels was 6°C (10°F). This setting allowed the control system to determine if the valve position being used was correct. Any lower temperature difference would cause a reduction in flow rate by the valve being closed slightly. Any higher temperature difference would cause an increase in flow rate until full open was obtained. After full flow, monitoring of the temperatures into and out of the array continued and valve adjustments were made accordingly. Although it proved completely satisfactory for our operation, a microprocessor and a variable valve is needed. Simplicity would be improved and extra expense eliminated if this procedure was not used. The loss

in energy during start-up due to less temperature gain would be minimal.

As the solar energy collection system reached the end of the day, shutdown was accomplished by comparing the returning collector water temperature to that of the storage tank. When this difference reached $3^{o}C$ ($5^{o}F$), the valve was completely closed and the pump shut down. This check temperature proved completely satisfactory. At no time during the project was there energy loss due to this temperature difference being too small. Microprocessor reaction for closing the valve was too slow in the initial system operation, but this was improved through programming changes. Again, a simpler valve with two positions would have been closed quickly and would have eliminated this problem with very little energy loss. Storage tank temperature gains during this shutdown procedure very rarely occurred at all.

The first temperature mentioned in the previous reports for use of the storage tank for house heating was $41^{o}C$ ($105^{o}F$). This was eventually lowered to $30^{o}C$ ($86^{o}F$). This temperature proved very satisfactory for supplying the thermal energy to heat the house, especially after the linear diffusers were installed to control the air flow from the heating ducts. The resulting $27^{o}C$ ($80^{o}F$) air used to heat the house did not cause discomfort or any other problems. The use of this temperature water from the storage tank was also sufficient to give some preheating to the domestic hot water by maintaining the heat exchanger at that level until the flow sensor demanded additional storage tank water. Settings other than this

would force the pump to the domestic water heat exchanger to work continuously.

7.8 "f" Chart

To put all the design parameters together in one design procedure usually requires the use of a computer. Numerous techniques exist to overcome the complexity of the analysis problem. These vary from using "rules of thumb" to complicated hand calculator computations. A system developed by researchers at the University of Wisconsin [6] has been used throughout solar energy designs. This method, known as "f" chart, was included in the Solar Heating System Design Workshop, conducted by the Civil Engineering School at the various Air Force bases [1].

Briefly, the "f" chart method takes a performance chart for solar heating system (Figure 7-1) and uses this to estimate the yearly output of a typical solar energy system. This analysis is a valuable design tool in that it allows relatively rapid calculations to be made whose accuracy exceeds the initial rough estimates. Cost comparisons can then be made using the predicted savings in fuel for heating to offset the capital investment in solar equipment.

Three calculations using the "f" chart method are shown in Appendix E. These calculations were designed to illustrate the effects of the various assumptions and parameters. When using the initial information on the Solar Test House available in the beginning of the project, columns one and two of Table 7-1 show the predicted performance of the solar heating system. The next column

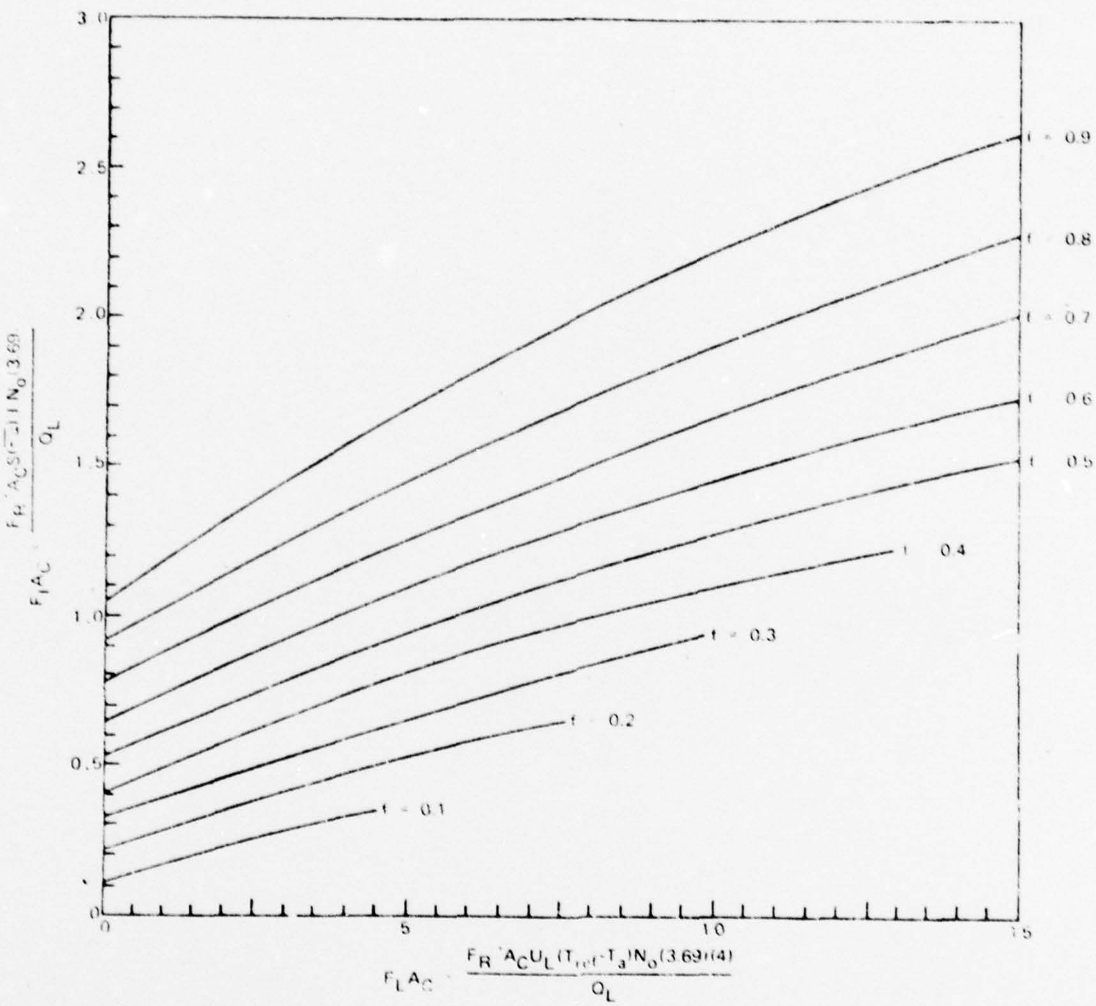

Figure 7-1. Fraction of Heating/DHW Load Supplied by Solar Energy [1]

illustrates the changes in the predictions if the lower heating demand and actual area of collectors is used. Since the actual yearly performance is approximately 60 per cent excluding domestic hot water, the use of the "f" chart requires some caution. The main problem is the value of the insolation taken from ASHRAE Chapter 59 [2] and used for the calculations. These were taken from data available for Colorado Springs, whose weather varies greatly from that at the site. If this difference in cloudiness is considered, the "f" chart would prove satisfactory for estimating the performance of typical solar heating systems. The monthly figures can also be used to estimate the relative performance of the solar energy system during the heating season. By varying the area of collectors, marginal effects of each additional collector can be estimated. When more accurate information is available for exact solar contribution to the domestic hot water requirements, this method of estimating the function supplied by solar energy should be even more satisfactory.

Heating Loss Rate ($Btu/ft^2/DD$)	Area of Collectors A_c (ft^2)	Fraction Supplied by Solar $\overline{f}$
15.80	500	0.49
15.80	600	0.57
7.83	546	0.73

Table 7-1. Results of "f" Chart Calculations

CHAPTER 8

CONCLUSIONS AND RECOMMENDATIONS

8.1 Conclusions

The conclusions from the experience gained on this project and the data analyzed by the researchers are the following:

a. Yearly performance improved throughout this reporting period to reach 60 per cent of the house heating demand being met by solar energy.

b. Bleed air valves in conjunction with a make-up water system cleared the air blockage problem in the solar collector arrays.

c. Further decreasing the storage tank water mass once again increased the time the energy in the tank could be used and increased the overall solar contribution to meeting the house heating demand.

d. Collector efficiency was sacrificed by reducing the flow rate to improve overall system efficiency.

e. The energy conservation techniques employed throughout the project effectively reduced the house heating demand.

f. Thermography can be used to detect air blockages and aid in the observation of the clearing efforts.

g. The various parameters used to design the system originally were shown to be valid for this application.

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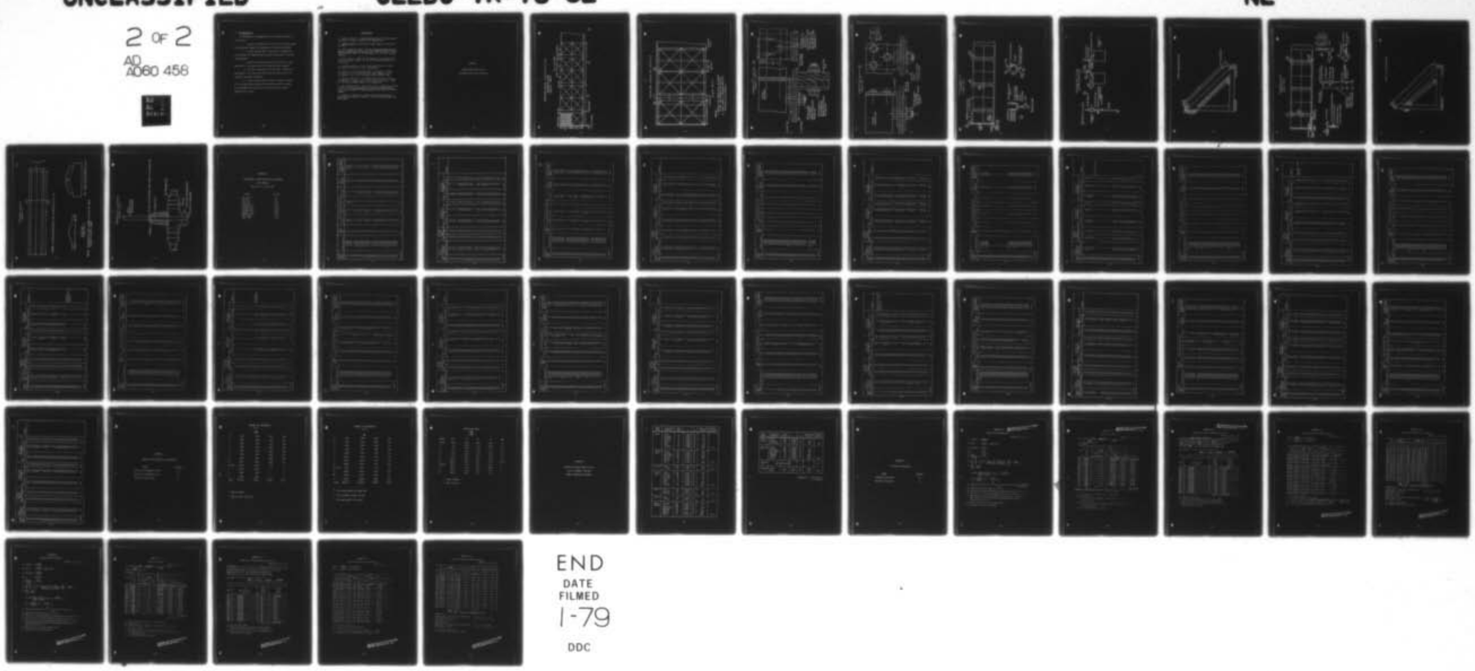

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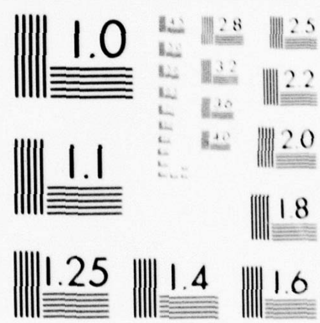

MICROCOPY RESOLUTION TEST CHART

8.2 Recommendations

The following are recommendations for continued research on this project:

a. Continue to monitor the effects of the various system and operational changes for comparison to previous performance.

b. Install the mini-micro controller to determine its effectiveness for simplified and accurate controlling of the solar energy systems.

c. Install the evacuated tube solar collectors to gain experience in the operation of this advanced system component.

d. With both collectors set at 52^{o} slope, compare the performance of the flat plate solar collectors with that of the evacuated tube solar collectors.

e. Allow the solar energy system to attempt to supply all the thermal energy during a sunny winter period to discover the environment that would exist in the house under complete dependence on the sun.

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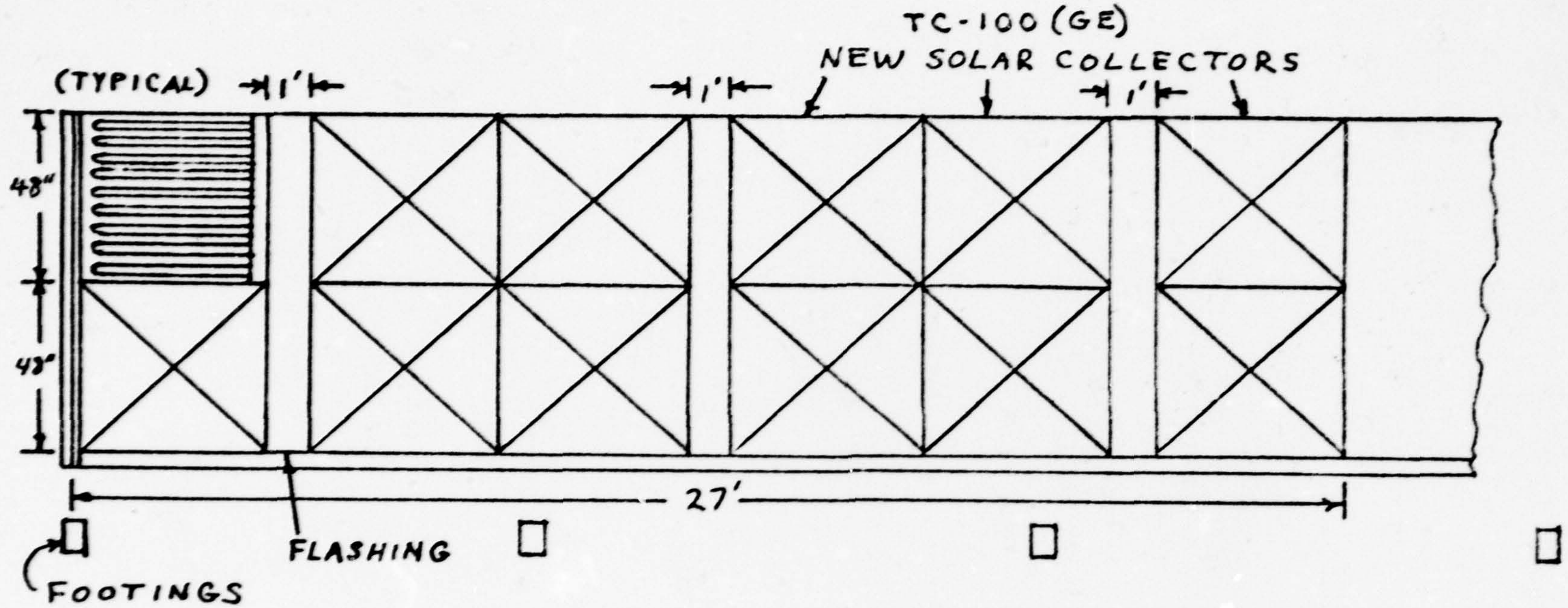
APPENDIX A

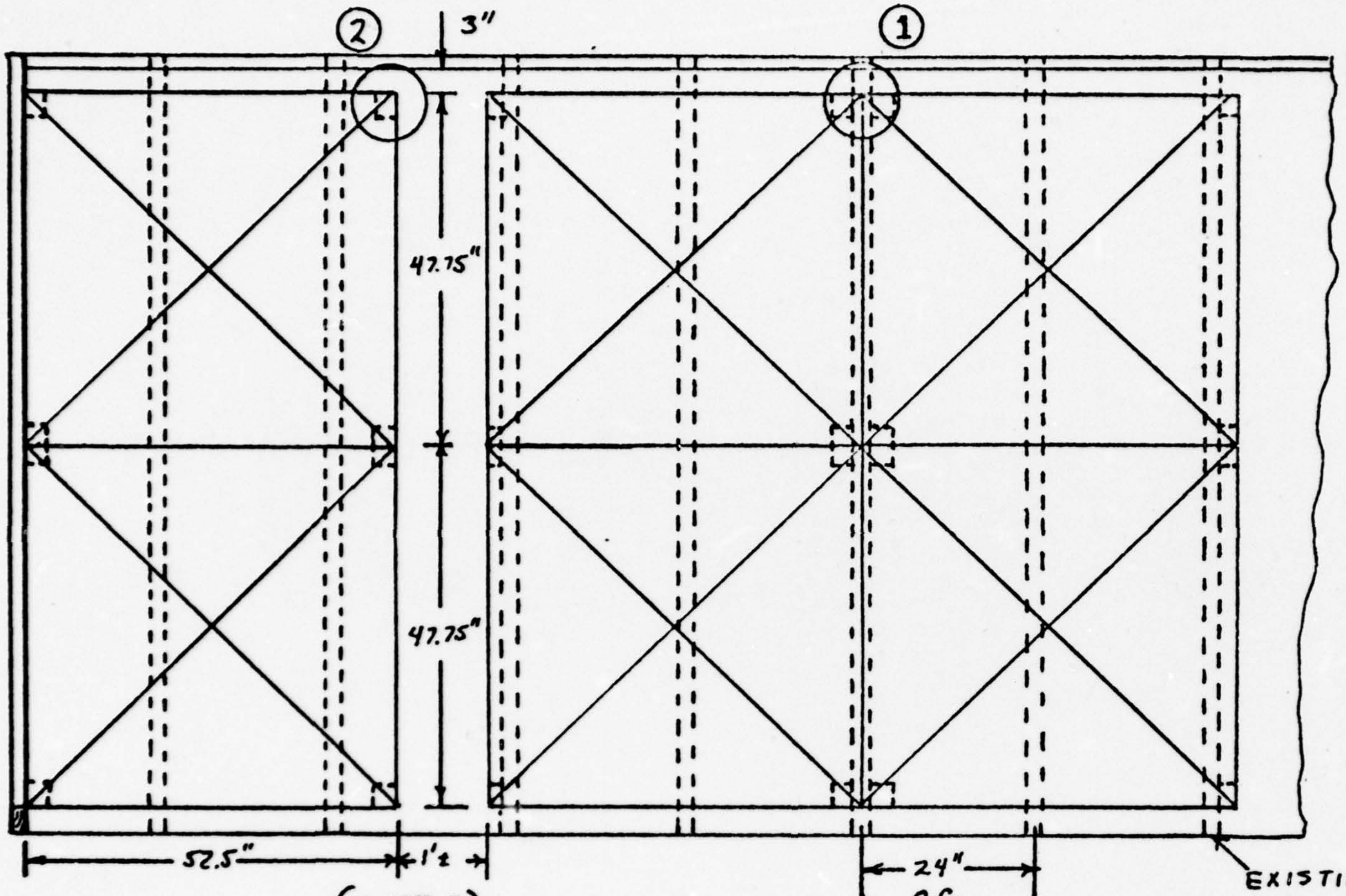
GROUND ARRAY MODIFICATION

EVACUATED TUBE SOLAR COLLECTORS

GROUND ARRAY MODIFICATION
GENERAL PLAN
SCALE: 1/4" = 1'



COLLECTOR CONNECTOR DETAILS

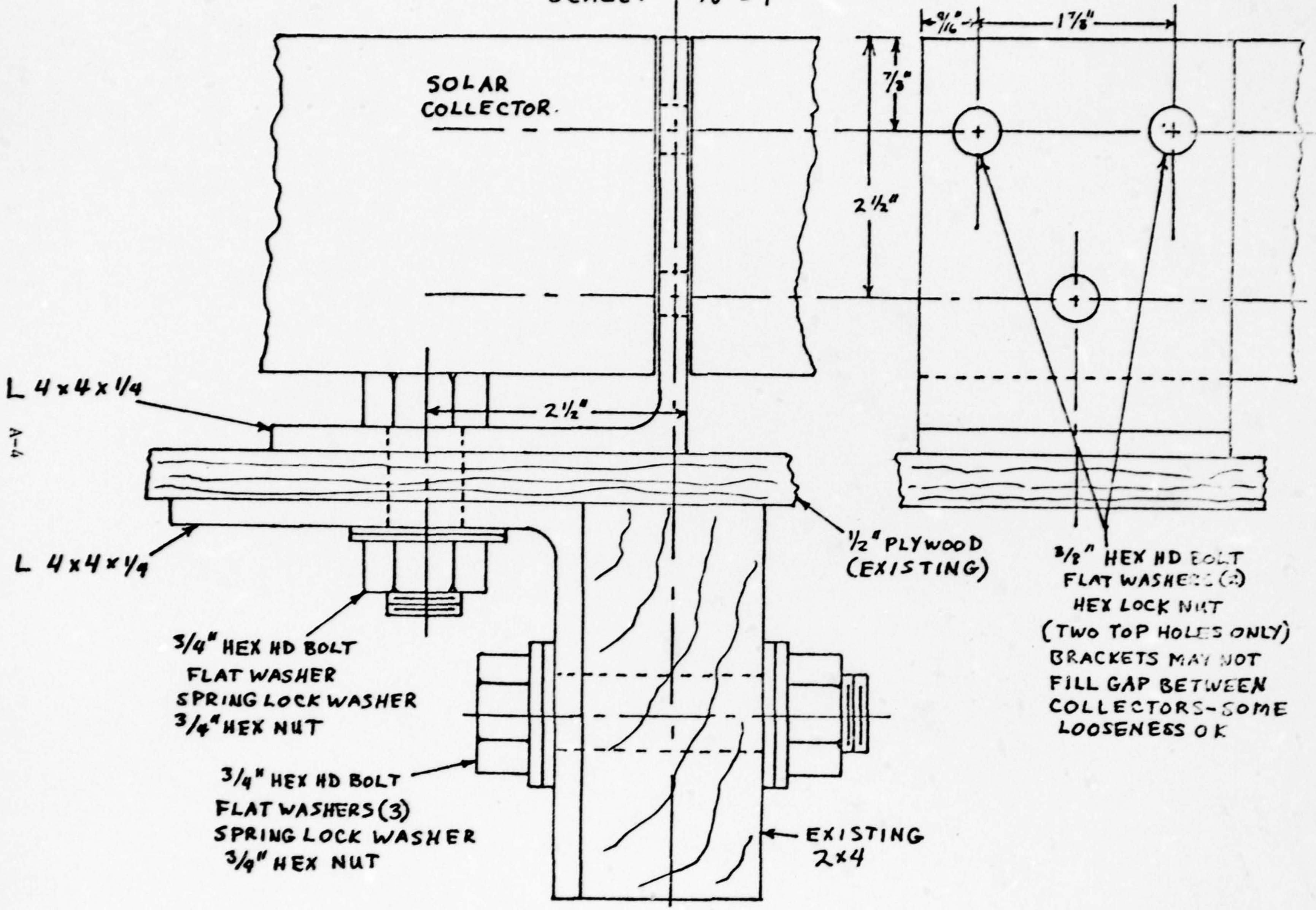


SCALE: ½" = 1'

NOTES:

1. GROUP OF FOUR COLLECTORS TO BE CENTERED ON 2x4'S
2. ONE FOOT ± ADJUSTMENTS TO COMPLY WITH NOTE 1.

CONNECTION DETAIL (1)
SCALE: 7/8" = 1"



CONNECTION DETAIL (2)
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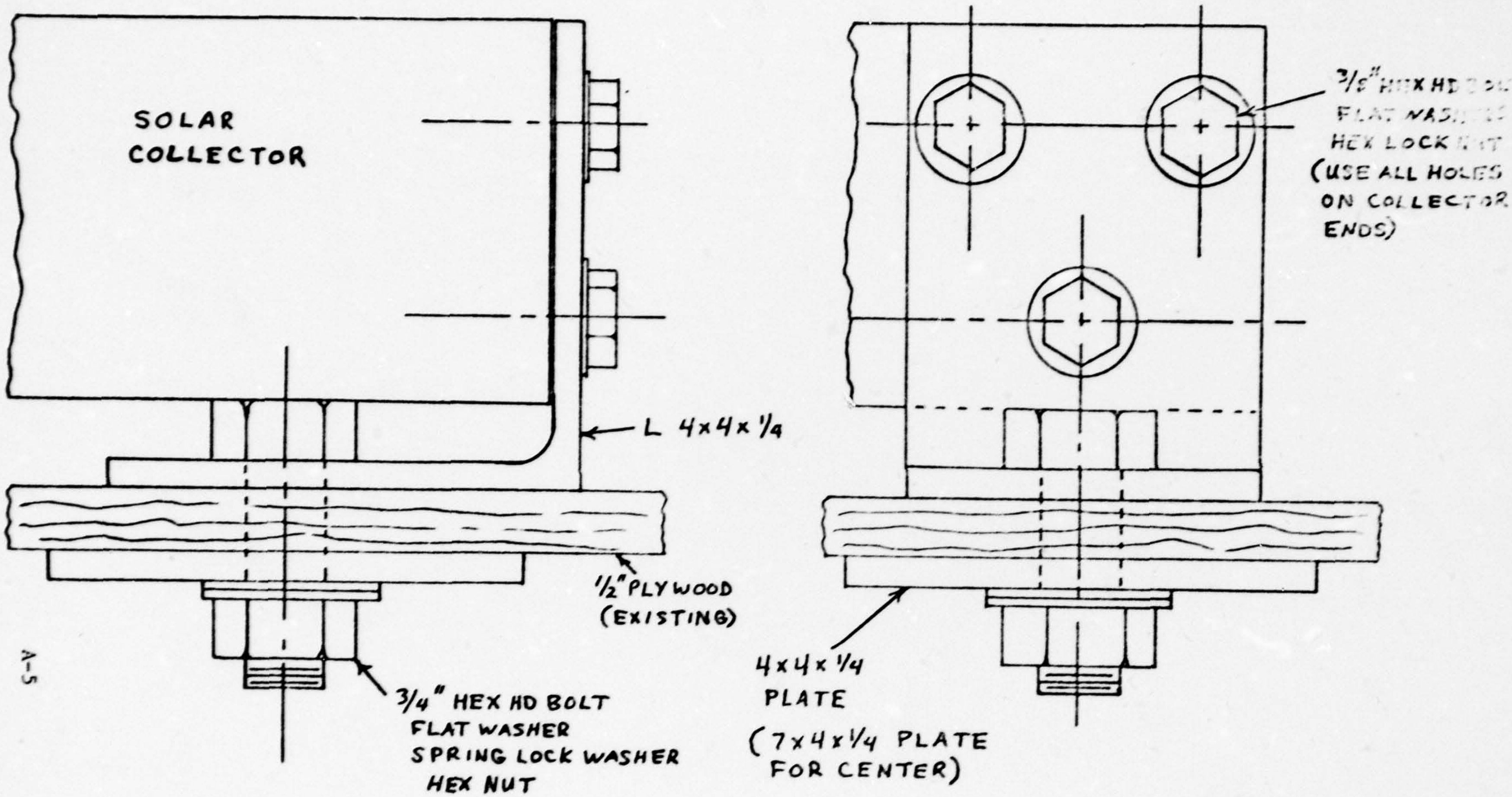
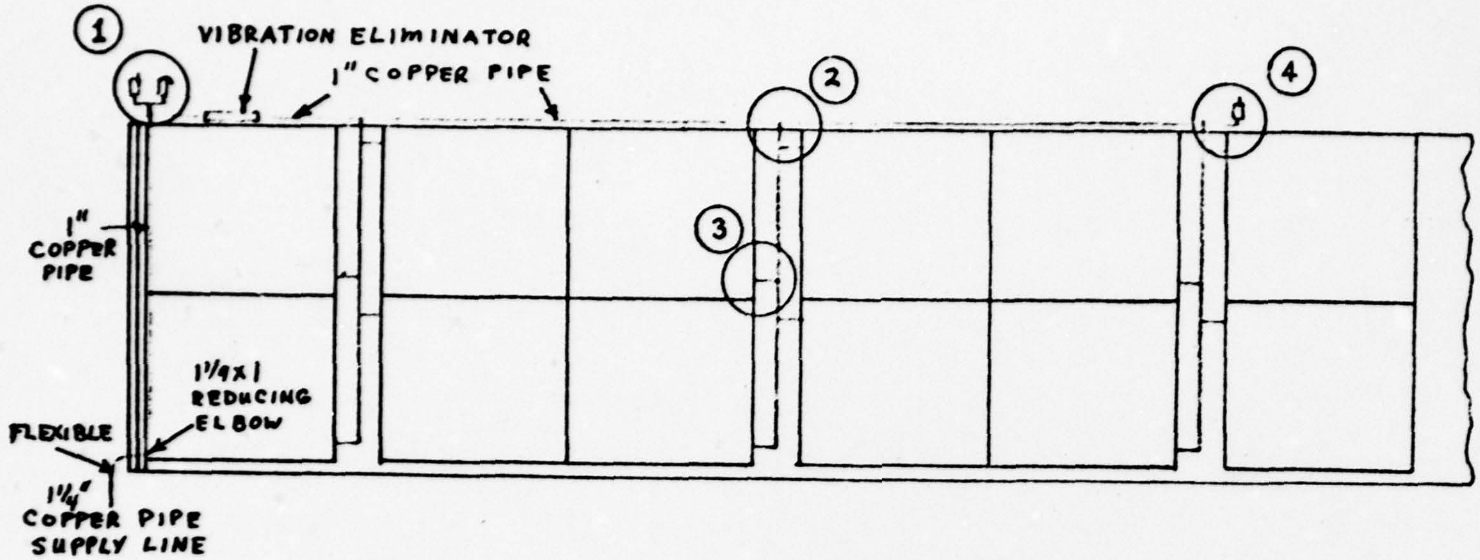
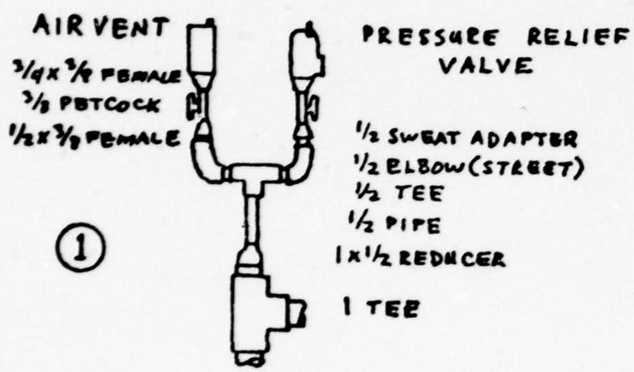
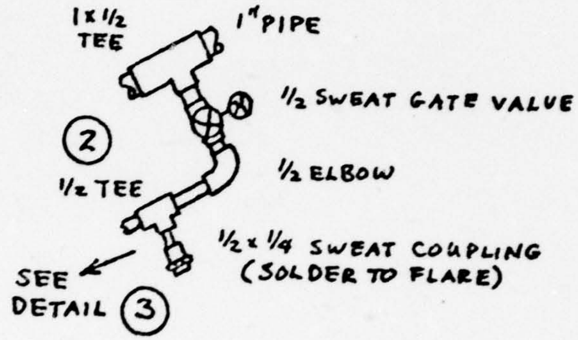


PLUMBING PLAN
(SUPPLY)
SCALE : 1/4" = 1'



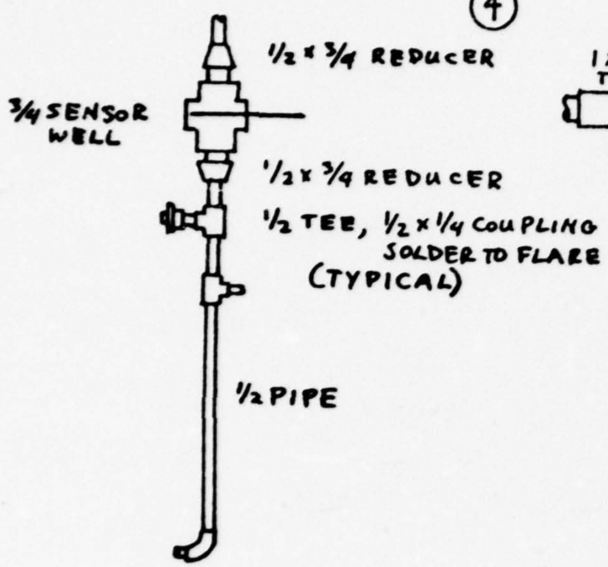


(SEE END VIEW)

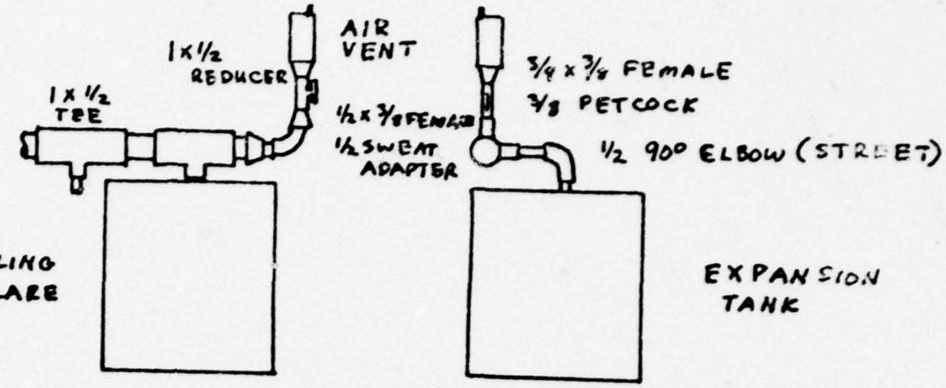


PLUMBING PLAN
(SUPPLY DETAILS)

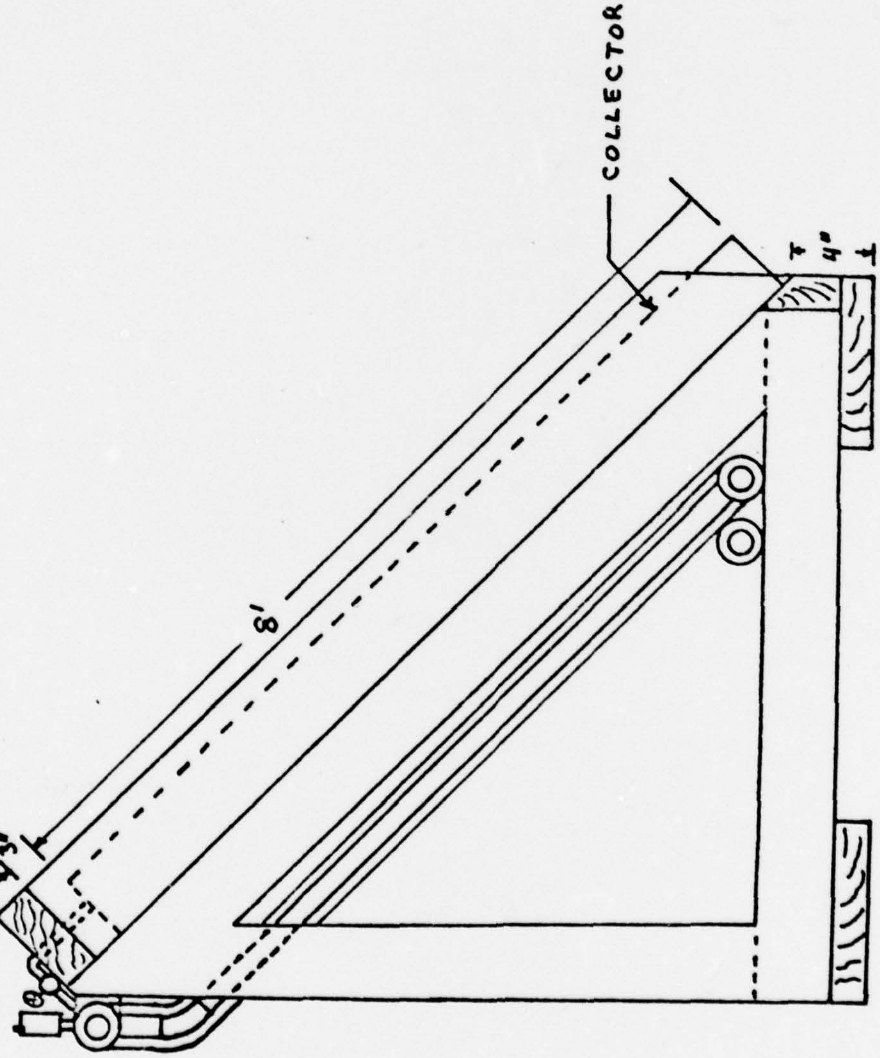
③ (OFFSET TO LEFT)



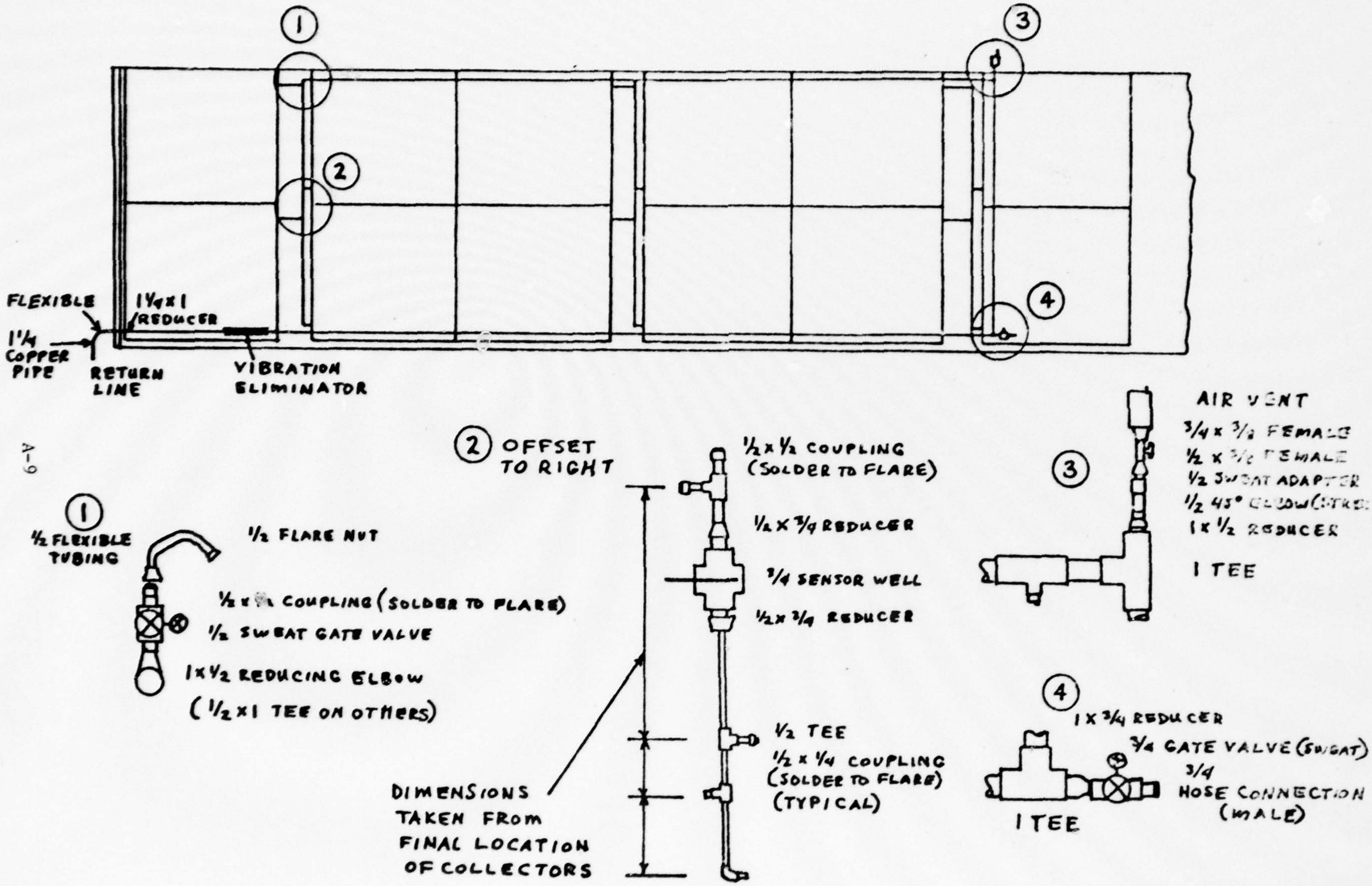
④



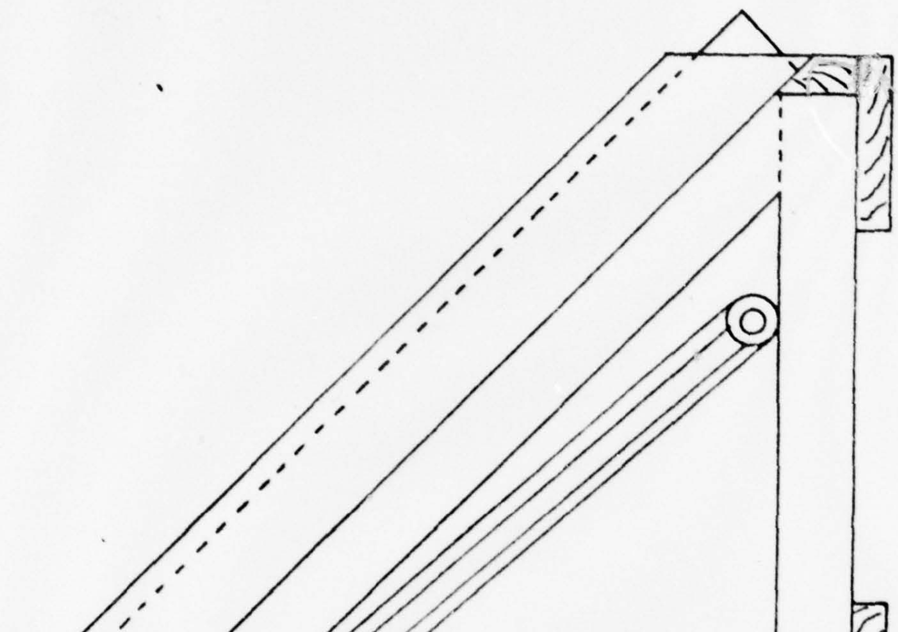
END VIEW (SUPPLY)



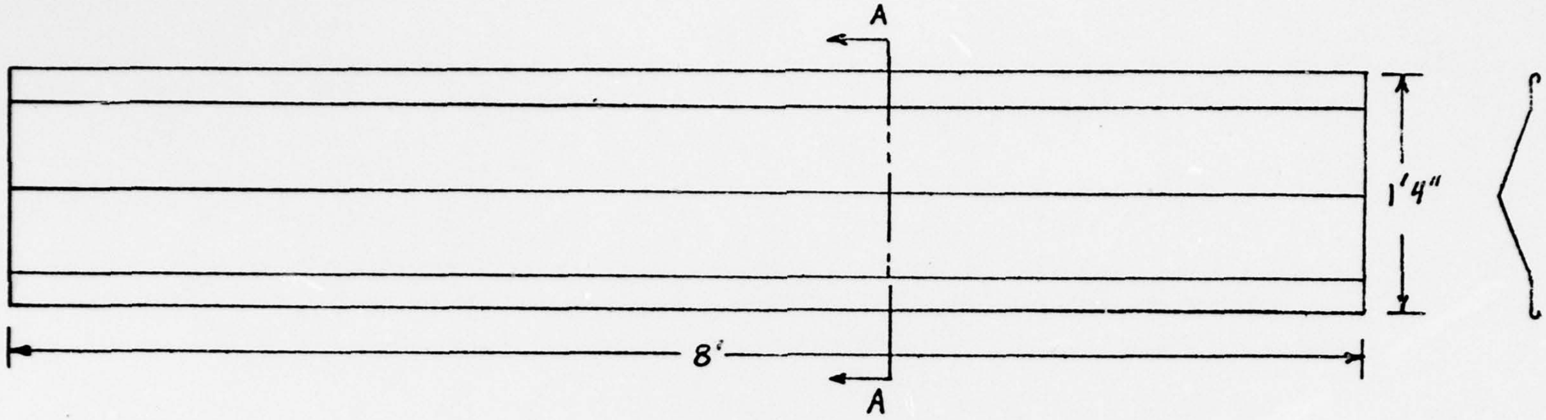
PLUMBING PLAN
(RETURN)
SCALE: 1/4" = 1'



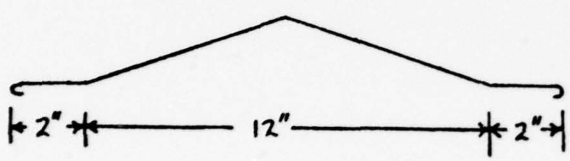
END VIEW (RETURN)



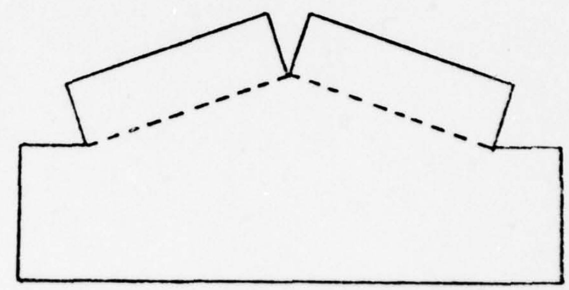
FLASHING DETAILS
SCALE: 1" = 1'



THREE - 20 GA GALVANIZED CRS FLASHING WITH LIP

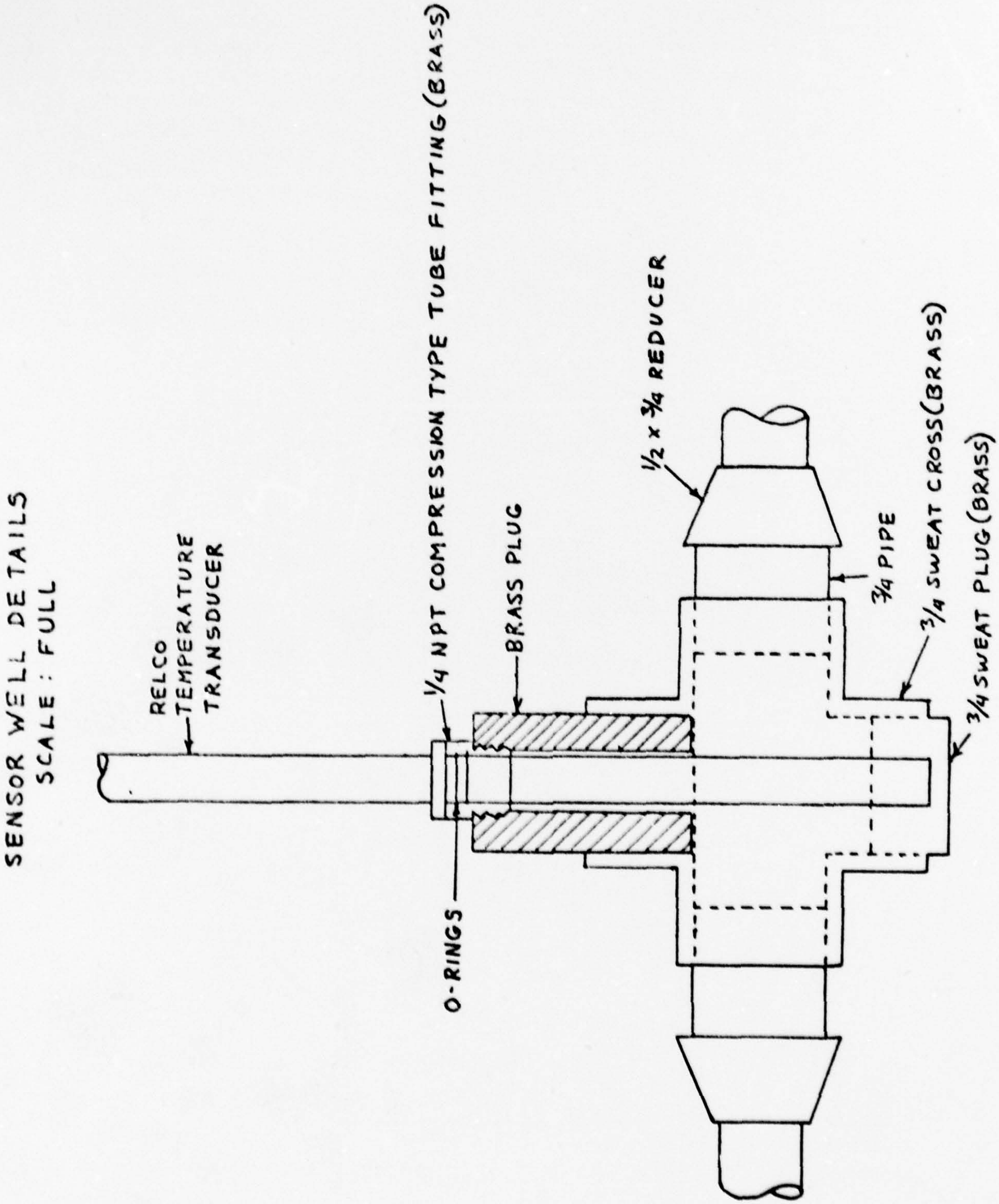


VIEW A-A
SCALE: 3/16" = 1"



SIX - END PIECES (SAME STEEL)

NOTE: MATERIALS AND FABRICATION BY BCE (SHEET METAL SHOP)


SENSOR WELL DETAILS
SCALE : FULL
RELCO TEMPERATURE TRANSDUCER
1/4 NPT COMPRESSION TYPE TUBE FITTING (BRASS)
O-RINGS
BRASS PLUG
1/2 x 3/4 REDUCER
3/4 PIPE
3/4 SWEAT CROSS (BRASS)
3/4 SWEAT PLUG (BRASS)

APPENDIX B

SOLAR ENERGY SYSTEM TABULARIZED PERFORMANCE

DATA SUMMARY

(April 1977 to April 1978)

Julian Date April	Time Interval	Degree Days (^{o}F)	House Heating Demand (MJ)				Time Interval Analysis	Average Hourly Heating Demand MJ/Hour
			Total	Solar	Gas	% Solar		
91	0-2348	29	214	204	10	95	24	8.92
92	0-2350	37	220	0	220	0	24	9.17
93	0-2345	21	240	0	240	0	24	10.00
94	0-1800	34	117	0	117	0	16	7.31
95	--	25	--	--	--	--	--	--
96	0-1600	21	112	103	9	92	15	7.47
97	715-2345	17	0	0	0	0	17	0
98	0-2345	16	112	112	0	100	24	4.67
99	0-1700	12	116	116	0	100	15	7.73
100	707-2345	4	0	0	0	0	17	0
101	0-2345	22	19	19	0	100	24	0.79
102	0-2000	26	187	187	0	100	23	8.13
103	0-2345	22	82	62	20	76	23	2.70
104	0-1700	20	153	153	0	100	10	--
105	--	--	--	--	--	--	--	--
106	0-2345	20	32	0	32	0	24	1.33
107	0-2345	17	85	77	8	91	24	3.54
108	0-2345	21	103	103	0	100	23	4.48
109	0-2345	27	199	199	0	100	22	5.41
110	0-2345	30	219	195	24	89	24	9.13
111	0-2350	24	131	45	86	34	24	5.46
112	0-2345	21	130	130	0	100	24	5.40
113	0-1700	17	99	99	0	100	17	5.71
114	215-2345	18	58	58	0	100	20	2.88
115	0-2345	17	84	84	0	100	23	3.65
116	0-2345	15	65	65	0	100	24	2.70
117	0-2345	5	54	54	0	100	22	2.51
118	0-2345	13	124	124	0	100	23	5.44
119	0-2300	14	15	15	0	100	15	1.01
120	0-2345	12	22	22	0	100	17	1.34
Totals		603	3024	2226	798	74	607	4.99

Julian Date April	Solar Insolation $MJ/m^2/Day$ Cum, Horizontal	Storage Tank Temp Daily		Ground Array Performance			Roof Array Performance			Remarks
		Start °C	Finish °C	MJ Available	MJ Collected	%	MJ Available	MJ Collected	%	
91	15.8	28	32	357.	121	34	379	144	38	
92	5.2	30	29	116	0	0	124	0	0	
93	15.8	28	29	357	93	26	380	0	0	
94	12.0	28	28	266	66	25	284	0	0	
95	--	--	--	--	--	--	--	--	--	
96	19.5	29	39	433	359	83	461	414	90	
97	16.7	31	38	365	209	57	390	294	75	
98	18.2	32	39	378	138	37	407	312	77	
99	17.1	33	46	356	264	74	383	277	72	
100	14.4	43	47	303	156	51	326	190	58	
101	8.6	43	43	164	35	22	179	43	24	
102	15.5	34	41	319	136	43	344	127	37	
103	10.9	33	37	223	119	54	240	126	52	
104	5.0	29	29	87	7	8	96	12	12	
105	--	--	--	--	--	--	--	--	--	
106	23.6	32	38	--	--	--	--	--	--	
107	22.5	33	45	415	311	75	456	282	62	
108	13.1	43	43	242	134	55	266	146	55	
109	5.6	36	36	101	2	2	111	0	0	
110	15.2	26	31	285	179	63	312	195	63	
111	24.0	28	39	429	293	68	474	304	64	
112	24.0	31	43	409	161	39	450	60	13	
113	16.7	36	41	282	71	25	311	34	11	
114	19.0	36	43	357	116	32	385	45	12	
115	20.9	38	47	424	135	32	452	53	12	
116	18.6	40	46	318	100	32	350	39	11	
117	17.1	41	46	317	82	26	344	30	9	
118	12.6	41	42	200	52	26	223	13	6	
119	17.9	39	42	268	145	54	301	59	20	
120	6.4	39	46	77	10	13	90	3	3	
Totals	15.2	37	43	7848	3493	45	8518	3203	38	

Julian Date May	Time Interval	Degree Days (^{o}F)	House Heating Demand (MJ) Total	Solar	Gas	% Solar	Time Interval Analysis	Average Hourly Heating Demand MJ/Hour
121	0-2345	10	0	0	0	0	22	0.00
122	0-2345	12	15.	15	0	100	22	0.68
123	0-2345	8	18	18	0	100	23	0.78
124	0-2330	11	0	0	0	0	24	0.00
125	0-2345	14	19	19	0	100	24	0.79
126	0-2345	8	27	27	0	100	18	1.53
127	0-2345	6	0	0	0	0	24	0.00
128	--	6	--	--	-	--	--	--
129	0-2345	4	0	0	0	0	18	0.00
130	0-2345	5	0	0	0	0	23	0.00
131	0-2345	11	32	32	0	100	23	1.37
132	0-2352	7	0	0	0	0	23	0.00
133	0-2358	9	30	30	0	100	23	1.28
134	0-2345	14	121	121	0	100	18	6.88
135	0-2345	10	0	0	0	0	20	0.00
136	0-2345	9	0	0	0	0	24	0.00
137	0-2345	3	13	13	0	100	18	0.69
138	0-2100	11	15	15	0	100	20	0.74
139	659-2350	16	67	67	0	100	17	3.94
140	0-2345	21	108	108	0	100	23	4.71
141	0-2100	19	37	37	0	100	21	1.72
142	--	17	--	--	-	--	--	--
143	0-2345	8	14	14	0	100	24	0.57
144	0-2345	7	0	0	0	0	19	0.00
145	0-2345	8	0	0	0	0	24	0.00
146	0-2345	7	0	0	0	0	24	0.00
147	0-2345	10	12	12	0	100	21	0.56
148	0-2345	15	0	0	0	0	24	0.00
149	0-2345	8	13	13	0	100	**	-0.24
150	0-2345	4	0	0	0	0	24	0.00
151	0-2345	3	0	0	0	0	22	0.00
Totals		297	542	542	0	100	555	0.98

Julian Date May	Solar Insolation $MJ/m^2/Day$ Cum, Horizontal	Storage Tank Temp Daily		Ground Array Performance			Roof Array Performance			Remarks
		Start °C	Finish °C	MJ Available	MJ Collected	%	MJ Available	MJ Collected	%	
121	15.1	44	44	253	131	51	279	21	8	
122	25.3	42	48	397	263	66	444	52	12	
123	19.8	44	48	306	87	28	343	30	9	
124	24.8	46	52	388	199	51	435	52	12	
125	24.3	49	52	378	15	40	423	38	9	
126	22.8	48	53	380	17	46	420	49	12	
127	21.8	52	55	408	16	40	440	46	11	
128	--	--	--	--	--	--	--	--	--	
129	16.2	53	56	256	143	56	287	37	13	
130	19.8	53	57	285	13	45	324	34	11	
131	22.5	54	57	328	157	47	372	38	10	
132	26.0	55	57	342	256	75	391	79	20	
133	15.4	57	57	242	62	27	371	28	10	
134	21.3	43	48	319	112	35	395	32	9	
135	17.7	46	50	253	77	31	286	23	8	
136	24.0	47	50	337	12	36	384	31	8	
137	17.3	48	51	231	90	39	265	20	7	
138	25.2	48	52	360	165	46	408	34	8	
139	7.6	49	47	108	0	0	123	0	0	
140	17.5	39	42	234	97	42	268	18	7	
141	25.7	39	44	348	17	50	399	15	4	
142	--	--	--	--	--	--	--	--	--	
143	25.5	41	46	387	126	33	434	30	7	
144	14.3	44	46	398	59	15	408	17	4	
145	20.9	43	48	269	97	36	311	42	14	
146	20.8	44	48	268	98	37	311	38	12	
147	15.6	45	47	208	6	30	239	24	10	
148	10.9	45	44	131	28	21	153	15	10	
149	20.4	42	47	284	202	71	324	105	32	
150	26.0	43	51	336	26	78	388	129	33	
151	22.0	48	51	284	196	69	328	101	31	
Totals	18.0	46	49	8721	3883	45	9815	1179	12	

Julian Date June	Time Interval	Degree Days (oF)	House Heating Demand (MJ)				Time Interval Analysis	Average Hourly Heating Demand MJ/Hour
			Total	Solar	Gas	% Solar		
152	0-2345	2	0	0	0	0	22	0.00
153	0-2345	2	0	0	0	0	24	0.00
154	0-2345	0	0	0	0	0	23	0.00
155	0-2345	0	0	0	0	0	19	0.00
156	0-2345	-	0	0	0	0	23	0.00
157	0-2345	-	0	0	0	0	22	0.00
158	0-2345	-	0	0	0	0	24	0.00
159	0-2345	-	0	0	0	0	24	0.00
160	0-2345	-	0	0	0	0	24	0.00
161	0-2345	-	0	0	0	0	22	0.00
162	0-2345	-	0	0	0	0	23	0.00
163	0-2345	-	0	0	0	0	4	0.00
164	0-2345	-	0	0	0	0	23	0.00
165	0-1400	-	0	0	0	0	14	0.00
166	100-2345	-	0	0	0	0	21	0.00
167	0-2345	-	0	0	0	0	23	0.00
168	0-2345	-	0	0	0	0	19	0.00
169	0-2345	-	0	0	0	0	23	0.00
170	0-1600	-	0	0	0	0	9	0.00
171	25-2345	-	0	0	0	0	23	0.00
172	0-2345	-	0	0	0	0	22	0.00
173	0-2345	-	0	0	0	0	24	0.00
174	0-2345	1	0	0	0	0	24	0.00
175	0-2345	5	0	0	0	0	23	0.00
176	0- 500	0	0	0	0	0	5	0.00
177	--	0	-	-	-	-	--	--
178	1001-2345	0	0	0	0	0	11	0.00
179	0-2345	0	0	0	0	0	20	0.00
180	0-2345	0	0	0	0	0	23	0.00
181	0-1600	5	0	0	0	0	16	0.00
Totals		20	0	0	0	0	578	0.00

Julian Date June	Solar Insolation MJ/m^2/Day Cum, Horizontal	Storage Tank Temp Daily		Ground Array Performance			Roof Array Performance			Remarks
		Start °C	Finish °C	MJ Available	MJ Collected	%	MJ Available	MJ Collected	%	
152	16.5	48	51	202	159	79	233	79	34	
153	15.8	49	51	184	86	47	214	38	18	
154	18.8	48	53	237	230	97	272	91	33	
155	16.1	51	51	190	194	103	221	63	29	
156	21.8	50	54	219	191	87	235	82	32	
157	20.7	52	56	281	289	103	320	104	32	
158	21.4	54	56	257	225	88	298	75	25	
159	23.3	54	57	286	231	116	331	103	31	
160	20.4	54	58	246	165	67	285	83	29	
161	19.4	56	58	239	170	73	275	81	29	
162	17.4	57	58	214	119	55	246	61	25	
163	0.2	-18	58	7	0	0	7	0	0	
164	18.0	56	57	218	171	79	252	73	29	
165	18.4	55	56	218	132	60	251	73	29	
166	31.5	56	62	254	178	70	296	84	29	
167	27.5	61	64	328	328	69	381	466	123	
168	20.5	62	64	257	140	55	296	208	70	
169	14.2	62	62	145	57	37	166	21	12	
170	3.6	60	61	69	19	14	73	2	2	
171	9.0	58	58	71	91	128	86	18	21	
172	17.1	55	56	188	250	138	221	34	15	
173	23.7	53	56	276	435	157	320	64	20	
174	15.1	53	54	209	244	117	237	45	19	
175	14.2	51	51	168	50	30	195	10	5	
176	0.0	49	49	2	0	0	2	0	0	
177	--	--	--	--	--	--	--	--	--	
178	13.2	52	54	180	164	90	205	48	24	
179	14.4	51	52	184	125	68	210	37	18	
180	21.6	47	52	248	223	90	287	79	27	
181	22.3	49	49	283	257	90	325	79	24	
Totals	17.0	51	55	5858	4912	84	6758	2201	33	

Julian Date July	Time Interval	Degree Days (^{o}F)	House Heating Demand (MJ)				Time Interval Analysis	Average Hourly Heating Demand MJ/Hour
			Total	Solar	Gas	% Solar		
182	--	-	-	-	-	-	--	--
183	1115-2345	0	0	0	0	0	13	0.00
184	0-2345	0	0	0	0	0	24	0.00
185	0-1930	0	0	0	0	0	20	0.00
186	215-1006	0	0	0	0	0	7	0.00
187	0-1631	0	0	0	0	0	10	0.00
188	--	0	-	-	-	-	--	--
189	--	1	-	-	-	-	--	--
190	--	4	-	-	-	-	--	--
191	--	0	-	-	-	-	--	--
192	--	0	-	-	-	-	--	--
193	--	0	-	-	-	-	--	--
194	--	0	-	-	-	-	--	--
195	--	0	-	-	-	-	--	--
196	--	0	-	-	-	-	--	--
197	--	0	-	-	-	-	--	--
198	--	0	-	-	-	-	--	--
199	1215-2345	0	0	0	0	0	11	0.00
200	0-2345	0	0	0	0	0	21	0.00
201	0-1900	3	0	0	0	0	18	0.00
202	959-2354	2	0	0	0	0	14	0.00
203	0-2345	0	0	0	0	0	23	0.00
204	0-2345	0	0	0	0	0	23	0.00
205	0-2345	0	0	0	0	0	23	0.00
206	0-2345	4	0	0	0	0	21	0.00
207	0.2345	0	0	0	0	0	24	0.00
208	0-2345	0	0	0	0	0	24	0.00
209	0-2345	0	0	0	0	0	24	0.00
210	0-1900	0	0	0	0	0	19	0.00
211	15-2345	0	0	0	0	0	24	0.00
212	0-1630	2	0	0	0	0	17	0.00
Totals		16	0	0	0	0	359	0.00

Julian Date July	Solar Insolation $MJ/m^2/Day$ Cum, Horizontal	Storage Tank Temp Daily		Ground Array Performance			Roof Array Performance			Remarks
		Start °C	Finish °C	MJ Available	MJ Collected	%	MJ Available	MJ Collected	%	
182	--	--	--	--	--	--	--	--	--	
183	15.5	52	55	204	245	120	235	66	28	
184	21.7	52	52	253	490	195	295	85	29	
185	24.2	48	53	2013	228	11	1908	92	5	
186	2.4	52	52	188	0	0	178	0	0	
187	2.4	48	54	85	1	1	84	0	0	
188	--	--	--	--	--	--	--	--	--	Data system work
189	--	--	--	--	--	--	--	--	--	
190	--	--	--	--	--	--	--	--	--	
191	--	--	--	--	--	--	--	--	--	
192	--	--	--	--	--	--	--	--	--	
193	--	--	--	--	--	--	--	--	--	
194	--	--	--	--	--	--	--	--	--	
195	--	--	--	--	--	--	--	--	--	
196	--	--	--	--	--	--	--	--	--	
197	--	--	--	--	--	--	--	--	--	
198	--	--	--	--	--	--	--	--	--	
199	12.6	53	58	166	148	89	192	113	58	
200	16.4	54	61	227	119	53	259	65	25	
201	15.5	58	59	217	127	59	246	23	10	
202	4.9	56	55	71	0	0	81	0	0	
203	16.8	51	54	246	139	57	277	43	15	
204	19.9	52	57	277	136	49	315	62	20	
205	14.9	54	57	206	92	45	234	40	17	
206	5.2	54	53	76	0	0	85	0	0	
207	17.4	49	54	258	135	52	291	52	18	
208	14.1	50	51	201	48	24	227	11	5	
209	18.9	19	32	388	48	12	413	50	12	
210	22.4	32	47	346	170	49	386	49	13	
211	18.4	44	50	281	70	25	314	23	7	
212	20.9	47	57	334	15	46	372	57	15	
Totals	13.7	48	53	6036	2350	39	6303	830	13	

Julian Date August	Time Interval	Degree Days (^{o}F)	House Heating Demand (MJ)				Time Interval Analysis	Average Hourly Heating Demand MJ/Hour
			Total	Solar	Gas	% Solar		
213	1615-2345	2	0	0	0	0	8	0.00
214	0-2345	0	0	0	0	0	22	0.00
215	0-2345	0	0	0	0	0	24	0.00
216	0-2345	0	0	0	0	0	21	0.00
217	0-2015	5	0	0	0	0	13	0.00
218	415-2345	0	0	0	0	0	20	0.00
219	0-2345	0	0	0	0	0	24	0.00
220	0-2100	0	0	0	0	0	19	0.00
221	615-2345	0	0	0	0	0	18	0.00
222	0-2345	2	0	0	0	0	22	0.00
223	0-2345	11	0	0	0	0	24	0.00
224	0-2345	1	0	0	0	0	24	0.00
225	0-2345	0	0	0	0	0	24	0.00
226	0-2345	0	0	0	0	0	17	0.00
227	0-2345	0	0	0	0	0	24	0.00
228	0-2345	4	0	0	0	0	24	0.00
229	0-2345	2	0	0	0	0	24	0.00
230	0-2345	0	0	0	0	0	24	0.00
231	0-2345	4	0	0	0	0	21	0.00
232	0-2345	2	0	0	0	0	22	0.00
233	0-2345	0	0	0	0	0	21	0.00
234	0-2345	0	0	0	0	0	18	0.00
235	0-2345	0	0	0	0	0	19	0.00
236	0-1600	0	0	0	0	0	16	0.00
237	1511-2345	0	0	0	0	0	4	0.00
238	0-2345	0	0	0	0	0	21	0.00
239	0-1945	7	0	0	0	0	20	0.00
240	0-2345	13	0	0	0	0	24	0.00
241	0-2345	1	0	0	0	0	22	0.00
242	0-2345	0	0	0	0	0	21	0.00
243	0-2345	2	0	0	0	0	23	0.00
Totals		56	0	0	0	0	628	0.00

Julian Date August	Solar Insolation MJ/m^2/Day Cum, Horizontal	Storage Tank Temp Daily		Ground Array Performance			Roof Array Performance			Remarks
		Start °C	Finish °C	MJ Available	MJ Collected	%	MJ Available	MJ Collected	%	
213	3.4	60	57	31	4	13	39	3	7	
214	17.0	56	56	266	214	80	296	70	24	
215	17.9	12	18	278	483	174	310	173	56	Lightning strike near STH
216	12.4	16	39	194	205	106	216	96	44	
217	9.4	37	42	151	54	36	168	19	11	
218	23.2	39	53	367	183	50	409	64	16	
219	21.8	50	62	411	112	27	382	57	15	
220	15.6	54	61	301	33	11	281	35	12	
221	19.2	53	63	365	61	17	340	80	24	
222	16.6	58	58	312	23	7	290	26	9	
223	4.6	55	55	89	0	0	83	0	0	
224	22.5	42	56	435	47	11	405	84	21	
225	20.4	49	60	395	41	10	368	62	17	
226	16.8	52	61	366	33	9	349	71	20	
227	12.7	54	56	266	17	7	252	19	7	
228	6.0	48	47	129	0	0	122	0	0	
229	8.7	41	42	180	2	1	171	5	3	
230	12.9	38	44	268	14	5	254	26	10	
231	13.6	39	47	283	114	5	267	31	12	
232	15.9	43	53	322	18	6	303	34	11	
233	18.8	49	56	390	34	9	368	42	11	
234	10.4	48	56	214	12	6	202	18	9	
235	17.1	38	58	362	30	8	344	62	18	
236	18.5	50	59	391	41	11	371	52	14	
237	1.1	60	60	23	0	0	22	1	7	
238	21.6	53	65	463	81	18	440	75	17	
239	15.7	54	58	357	20	5	342	43	13	
240	14.5	51	53	320	17	5	306	37	12	
241	21.2	47	60	469	46	10	447	111	25	
242	18.1	49	58	396	30	8	378	42	11	
243	20.6	54	61	458	48	10	438	101	23	
Totals	14.4	46	54	9252	1919	21	8963	1539	17	

Julian Date September	Time Interval	Degree Days (^{o}F)	House Heating Demand (MJ)				Time Interval Analysis	Average Hourly Heating Demand MJ/Hour
			Total	Solar	Gas	% Solar		
244	0-2345	1	0	0	0	0	23	0.00
245	0-2345	0	0	0	0	0	24	0.00
246	0-2345	0	0	0	0	0	24	0.00
247	0-2345	2	0	0	0	0	26	0.00
248	0-2345	4	0	0	0	0	16	0.00
249	0-2345	3	0	0	0	0	20	0.00
250	0-2345	0	0	0	0	0	24	0.00
251	0-2100	0	0	0	0	0	21	0.00
252	1917-2345	9	0	0	0	0	4	0.00
253	0-2345	8	0	0	0	0	20	0.00
254	0-2345	2	0	0	0	0	23	0.00
255	0-2345	9	0	0	0	0	23	0.00
256	0-2345	11	4	4	0	100	24	0.17
257	15-2345	12	0	0	0	0	24	0.00
258	0-2345	4	0	0	0	0	24	0.00
259	0-1315	8	0	0	0	0	14	0.00
260	1322-2345	1	0	0	0	0	11	0.00
261	0-2345	11	0	0	0	0	12	0.00
262	0-2345	10	0	0	0	0	22	0.00
263	0-2345	1	0	0	0	0	24	0.00
264	0-2345	7	19	19	0	100	23	0.82
265	0-2345	14	0	0	0	0	10	0.00
266	0-2345	13	0	0	0	0	24	0.00
267	0-2345	11	45	45	0	100	24	1.86
268	0-2345	6	0	0	0	0	20	0.00
269	0-2345	2	0	0	0	0	24	0.00
270	0-2345	8	0	0	0	0	24	0.00
271	0-2345	4	0	0	0	0	24	0.00
272	0-2345	3	0	0	0	0	24	0.00
273	0-2000	7	0	0	0	0	4	0.00
Totals		173	68	68	0	100	602	0.11

Julian Date September	Solar Insolation MJ/m^2 /Day Cum, Horizontal	Storage Tank Temp Daily		Ground Array Performance			Roof Array Performance			Remarks
		Start ^oC	Finish ^oC	MJ Available	MJ Collected	%	MJ Available	MJ Collected	%	
244	19.0	52	64	423	57	14	405	98	24	
245	14.2	54	57	335	25	7	323	49	15	
246	16.2	51	59	376	47	12	361	80	22	
247	17.7	53	61	411	41	10	396	75	19	
248	0.7	53	61	14	0	0	13	0	0	
249	13.9	52	61	324	123	38	312	71	23	
250	16.9	56	66	396	183	42	419	87	21	
251	18.5	58	66	434	183	42	419	87	21	
252	0.0	53	53	0	0	0	0	0	0	
253	12.3	50	56	295	70	24	285	36	13	
254	8.1	47	46	195	2	1	188	2	1	
255	6.6	42	43	160	20	12	155	6	4	
256	13.0	39	46	352	95	27	346	65	19	
257	19.9	42	56	498	198	40	484	221	46	
258	15.9	51	57	401	109	27	391	94	24	
259	7.3	51	51	185	17	9	181	18	10	
260	4.9	49	50	124	7	5	121	7	6	
261	3.7	47	57	95	15	16	93	7	7	
262	14.3	54	61	371	131	35	363	77	21	
263	19.4	52	63	510	285	56	499	152	31	
264	0.0	57	67	--	--	--	--	--	--	Pyranometer
265	0.0	57	60	--	--	--	--	--	--	removed and sent
266	0.0	57	64	--	--	--	--	--	--	to NOAA
267	0.0	56	67	--	--	--	--	--	--	
268	0.0	59	62	--	--	--	--	--	--	
269	0.0	58	67	--	--	--	--	--	--	
270	0.0	59	69	--	--	--	--	--	--	
271	0.0	59	67	--	--	--	--	--	--	
272	0.0	58	66	--	--	--	--	--	--	
273	0.0	58	62	--	--	--	--	--	--	
Totals	12.12	52	59	5899	1608	27	5716	1218	21	

Julian Date October	Time Interval	Degree Days (^{O}F)	House Heating Demand (MJ)				Time Interval Analysis	Average Hourly Heating Demand MJ/Hour
			Total	Solar	Gas	% Solar		
274	--	--	--	--	--	--	--	--
275	0-2345	24	147	147	0	100	24	6.14
276	0-2345	14	93	93	0	100	19	4.79
277	0-2345	10	0	0	0	0	22	0.00
278	0-2356	17	29	29	0	100	21	1.39
279	0-2345	18	142	142	0	100	21	6.72
280	0-2345	13	134	134	0	100	24	5.57
281	0-2315	21	158	158	0	100	23	6.95
282	0-2345	18	137	137	0	100	0	5.88
283	0-2345	27	111	111	0	100	20	5.53
284	0-2345	34	275	275	0	100	24	11.47
285	0-2345	26	202	202	0	100	10	19.93
286	0-2345	16	135	135	0	100	24	5.62
287	0-2345	12	73	73	0	100	15	4.92
288	0-2355	21	157	157	0	100	16	9.68
289	0-2345	12	94	94	0	100	18	5.25
290	0-2346	17	88	88	0	100	22	3.93
291	0-2345	15	122	122	0	100	24	5.09
292	0-2000	12	123	123	0	100	19	6.35
293	15- 445	7	50	50	0	100	5	10.52
294	0-2357	16	123	123	0	100	24	5.23
295	0-1730	23	232	232	0	100	18	13.07
296	0-1432	19	144	144	0	100	15	9.77
297	15-2345	16	111	111	0	100	20	5.70
298	0-2357	14	152	152	0	100	24	6.28
299	0-1000	13	111	111	0	100	10	10.82
300	403-2345	19	52	52	0	100	19	2.70
301	0-2345	16	133	133	0	100	24	5.56
302	0-2130	13	117	117	0	100	12	9.98
303	2015-2345	14	0	0	0	0	3	0.00
304	0-2345	26	155	155	0	100	17	9.18
Totals		546	3602	3602	0	100	560	6.43

Julian Date October	Solar Insolation $MJ/m^2/Day$ Cum, Horizontal	Storage Tank Temp Daily		Ground Array Performance			Roof Array Performance			Remarks
		Start °C	Finish °C	MJ Available	MJ Collected	%	MJ Available	MJ Collected	%	
274	--	--	--	--	--	--	--	--	--	
275	0.0	52	64	--	--	--	--	--	--	
276	0.0	52	62	--	--	--	--	--	--	
277	0.0	53	58	--	--	--	--	--	--	
278	0.0	51	51	--	--	--	--	--	--	
279	0.0	43	42	--	--	--	--	--	--	
280	0.0	36	51	--	--	--	--	--	--	
281	0.0	42	56	--	--	--	--	--	--	
282	0.0	45	57	--	--	--	--	--	--	
283	0.0	47	47	--	--	--	--	--	--	
284	0.0	34	48	--	--	--	--	--	--	
285	0.0	38	48	0	0	0	0	0	0	Pyranometer reinstalled
286	16.1	40	57	526	225	43	526	194	37	
287	2.1	47	59	74	30	40	74	18	24	
288	4.3	48	52	143	10	7	143	9	6	
289	8.4	47	58	287	125	43	287	103	36	
290	14.1	49	58	477	146	31	477	145	30	
291	15.1	49	64	521	201	39	521	178	34	
292	12.8	52	62	437	169	39	437	161	37	
293	0.0	49	49	0	0	0	0	0	0	
294	9.4	47	52	362	43	12	362	42	12	
295	7.9	39	42	296	33	11	296	29	10	
296	11.3	34	47	416	148	36	416	137	33	
297	9.9	42	44	382	65	17	382	41	11	
298	14.2	37	55	520	203	39	520	183	35	
299	2.1	43	43	98	0	0	98	2	2	
300	13.6	52	63	505	166	33	505	161	32	
301	13.2	49	62	888	184	21	888	167	19	
302	2.6	52	54	107	0	0	107	0	0	
303	0.0	54	54	0	0	0	0	0	0	
304	3.3	48	48	141	17	12	141	10	7	
Totals	5.9	45	53	6180	1765	29	6180	1580	26	

Julian Date November	Time Interval	Degree Days (°F)	House Heating Demand (MJ)				Time Interval Analysis	Average Hourly Heating Demand MJ/Hour
			Total	Solar	Gas	% Solar		
305	0-2345	38	272	272	0	100	21	13.23
306	0-2345	28	221	221	0	100	22	9.97
307	0-2345	23	230	230	0	100	23	9.83
308	0-2350	19	213	213	0	100	24	9.06
309	0-2345	13	146	146	0	100	23	6.27
310	0-2352	16	128	128	0	100	21	5.99
311	0-2345	22	187	187	0	100	22	8.65
312	0-2359	35	252	188	64	75	18	14.02
313	0-2354	43	219	64	154	29	21	10.35
314	0-2345	34	201	50	151	25	22	9.09
315	0-2345	28	215	173	43	80	22	9.61
316	0-2345	20	156	156	0	100	23	6.68
317	0-2345	23	155	44	111	28	24	6.45
318	0-2345	17	212	212	0	100	24	8.85
319	0-2345	22	204	204	0	100	20	10.33
320	0-2345	25	169	169	0	100	19	8.85
321	0-2345	34	245	245	0	100	18	13.29
322	0-2345	27	229	229	0	100	23	9.96
323	0-2345	33	268	268	0	100	24	11.17
324	0-2345	46	188	188	0	100	16	11.75
325	0-2345	43	332	76	256	23	21	16.04
326	0-2345	21	142	18	124	13	21	6.62
327	0-2345	30	188	91	97	48	19	9.97
328	0-2345	27	254	0	254	0	24	10.59
329	0-2353	27	131	0	131	0	24	5.43
330	0-2345	21	229	229	0	100	24	9.55
331	0-2357	35	295	175	121	59	23	12.69
332	0-2346	30	224	50	174	22	23	9.65
333	0-2345	33	298	143	155	48	24	12.42
334	0-2357	33	320	27	292	8	7	44.72
Totals		846	6525	4396	2128	67	642	10.16

Julian Date November	Solar Insolation $MJ/m^2/Day$ Cum.Horizontal	Storage Tank Temp Daily		Ground Array Performance			Roof Array Performance			Remarks
		Start °C	Finish °C	MJ Available	MJ Collected	%	MJ Available	MJ Collected	%	
305	12.2	37	51	473	154	34	473	115	24	
306	11.0	36	51	443	145	33	443	121	27	
307	12.8	39	54	518	170	33	517	137	26	
308	13.0	39	55	538	150	28	538	168	31	
309	8.9	44	52	381	75	20	381	75	20	
310	9.0	44	48	381	36	9	381	40	10	
311	6.7	40	42	295	21	7	295	14	5	
312	5.3	32	29	213	0	0	213	0	0	
313	9.7	28	34	402	13	32	402	0	0	
314	11.7	34	37	518	214	41	518	7	1	
315	11.6	29	44	594	199	34	594	87	15	
316	5.6	33	33	251	9	4	251	8	3	
317	11.5	29	44	498	19	39	498	109	22	
318	11.3	36	52	493	176	36	493	139	28	
319	5.1	40	38	237	0	0	237	0	0	
320	6.9	29	42	296	68	23	296	66	22	
321	9.0	33	43	404	142	35	404	93	23	
322	9.4	30	42	414	168	41	414	90	22	
323	9.3	29	41	411	141	34	411	102	25	
324	5.2	28	29	229	35	15	229	1	0	
325	8.2	27	31	381	99	26	381	66	17	
326	6.4	28	31	303	34	11	303	24	8	
327	4.3	28	33	220	30	14	220	32	15	
328	4.0	28	28	210	0	0	210	0	0	
329	9.9	27	40	481	134	38	481	112	23	
330	8.9	29	39	439	122	28	439	100	23	
331	5.3	29	31	269	9	3	269	20	8	
332	5.3	28	34	278	4	15	278	39	14	
333	8.1	29	34	416	98	24	416	74	18	
334	4.8	29	31	258	12	5	258	15	6	
Totals	7.7	32	39	11240	2854	25	11240	1855	17	

Julian Date December	Time Interval	Degree Days (°F)	House Heating Demand (MJ)				Time Interval Analysis	Average Hourly Heating Demand MJ/Hour
			Total	Solar	Gas	% Solar		
335	0- 530	39	95	0	95	0	6	16.60
336	1715-2356	24	51	0	51	0	7	7.38
337	0-2345	14	107	0	107	0	24	4.45
338	0-2345	24	161	134	27	83	24	6.71
339	0-2345	39	279	166	114	59	24	11.64
340	0-2356	33	300	92	207	31	20	15.36
341	0-2345	18	265	127	138	48	22	12.29
342	0- 800	38	129	118	10	92	8	15.59
343	603-2345	42	235	169	66	72	18	13.07
344	0-2345	26	233	81	152	35	24	9.72
345	0-2200	15	160	153	7	96	19	8.22
346	15-2345	25	225	225	0	100	24	9.46
347	0-2345	29	276	276	0	100	22	12.34
348	0-2357	15	186	156	30	84	19	9.60
349	0-2345	16	95	0	95	0	15	6.22
350	0-2345	32	165	165	0	100	18	8.95
351	0-2200	33	267	167	101	62	21	13.02
352	703-2345	26	106	73	34	68	16	6.78
353	0-2345	41	347	337	10	97	24	14.46
354	0-2345	46	322	185	137	57	21	15.28
355	0-2345	35	292	226	66	77	19	15.03
356	0-2100	29	216	115	102	53	18	11.84
357	715-2345	24	140	101	38	73	14	9.68
358	0-2345	36	367	295	71	81	24	15.27
359	0-2345	37	312	198	115	63	23	13.58
360	0-2345	41	346	305	42	88	24	14.43
361	0-2345	35	323	192	131	59	22	14.98
362	0-2345	39	283	138	145	49	21	13.41
363	0-2300	32	230	32	199	14	20	11.49
364	0-2345	29	344	77	267	22	24	14.33
365	0-2345	38	387	126	261	33	24	16.13
Totals		950	7244	4427	2817	61	610	11.88

Julian Date December	Solar Insolation $MJ/m^2/Day$ Cum, Horizontal	Storage Tank Temp Daily		Ground Array Performance			Roof Array Performance			Remarks
		Start °C	Finish °C	MJ Available	MJ Collected	%	MJ Available	MJ Collected	%	
335	0.0	28	28	. 0	0	0	0	0	0	
336	0.0	27	27	0	0	0	0	0	0	
337	7.1	26	34	359	92	26	359	71	20	
338	8.1	28	38	397	107	27	397	86	22	
339	5.1	29	32	262	-1	-3	262	21	8	
340	6.0	27	34	295	8	28	295	79	27	
341	7.3	29	42	364	110	30	364	83	23	
342	0.0	29	29	6	0	0	6	0	0	
343	7.3	28	34	366	139	38	366	82	22	
344	8.7	29	42	445	158	36	445	110	25	
345	5.2	29	46	292	101	35	292	115	39	
346	9.4	36	48	474	168	35	474	142	30	
347	6.3	35	43	354	3	9	354	48	14	
348	4.2	37	37	221	0	0	221	0	0	
349	1.0	28	36	98	0	0	98	1	2	
350	2.6	30	39	143	42	29	143	25	18	
351	9.0	29	33	450	177	39	450	134	30	
352	8.8	29	43	437	127	29	437	52	12	
353	7.6	29	37	393	99	25	393	122	31	
354	8.8	29	40	439	154	35	439	178	40	
355	3.1	29	39	173	60	35	173	63	36	
356	8.0	29	41	381	120	32	381	149	39	
357	6.1	29	39	317	113	36	317	111	35	
358	8.4	29	42	434	148	34	434	153	35	
359	9.0	31	41	473	159	34	473	169	36	
360	8.7	29	41	446	156	35	446	172	38	
361	4.6	29	34	244	27	11	244	33	13	
362	6.7	28	38	331	90	27	331	122	37	
363	2.8	29	29	140	0	0	140	2	1	
364	0.0	0	0	0	0	0	0	0	0	
365	0.0	0	0	0	0	0	0	0	0	
Totals	5.9	27	35	8733	2450	28	8733	2324	27	

Julian Date January	Time Interval	Degree Days (^{o}F)	House Heating Demand (MJ)				Time Interval Analysis	Average Hourly Heating Demand MJ/Hour
			Total	Solar	Gas	% Solar		
1	1115-2345	51	234	234	0	100	13	18.00
2	0-2345	46	429	193	235	45	24	17.88
3	0-2345	27	246	109	136	45	18	13.54
4	0-2350	27	382	51	331	13	23	16.62
5	0-1900	27	212	68	145	32	18	12.09
6	11-2345	25	299	151	148	50	19	15.50
7	0-2345	35	351	216	134	62	24	14.62
8	0-2345	38	427	285	141	67	24	18.03
9	0-2345	36	328	143	185	44	20	16.33
10	0-2359	48	342	25	317	7	20	17.39
11	0-2345	35	290	42	248	14	18	15.78
12	0-2348	28	278	28	250	10	21	13.44
13	0-2345	37	335	181	154	54	23	14.83
14	0-2353	38	378	36	342	10	22	16.92
15	0-2348	39	280	0	280	0	19	14.71
16	0-2345	52	357	0	357	0	20	18.29
17	0-2351	37	269	45	224	17	19	14.15
18	0-2350	41	299	49	250	17	20	15.16
19	0-2355	48	310	0	310	0	19	16.04
20	0-2352	41	339	75	264	22	20	16.93
21	115-2345	40	405	264	141	65	23	17.61
22	0-2345	37	407	251	156	62	22	18.50
23	0-2358	42	377	159	218	42	22	17.14
24	0-2355	46	359	126	233	35	21	17.10
25	0-2345	41	391	219	172	56	22	17.53
26	0-2345	39	386	220	166	57	22	17.95
27	0-2345	40	388	223	165	58	22	17.43
28	0-2345	42	432	24	408	5	23	18.46
29	0-2349	35	341	88	253	26	21	16.20
30	0-2357	38	194	0	194	0	13	15.47
31	0-2352	35	361	0	361	0	23	15.60
Totals		1191	10425	3507	6916	34	687	16.36

Julian Date January	Solar Insolation $MJ/m^2/Day$ Cum, Horizontal	Storage Tank Temp Daily Start °C	Finish °C	Ground Array Performance MJ Available	MJ Collected	%	Roof Array Performance MJ Available	MJ Collected	%	Remarks
1	5.7	31	37	276	112	41	0	0	0	
2	9.7	38	39	485	183	38	0	0	0	Replaced sensors on RA
3	2.0	29	34	110	0	0	110	33	30	Leak on GA, broken collector
4	5.3	29	30	275	36	13	275	68	25	
5	6.5	28	33	319	88	28	319	102	32	
6	6.0	29	37	287	101	35	287	112	39	
7	9.2	29	40	451	158	35	451	176	39	
8	7.6	29	37	365	130	36	365	145	40	
9	9.0	29	40	429	129	30	429	160	37	
10	4.2	29	29	188	4	2	188	13	7	
11	6.2	28	32	295	67	23	295	70	24	
12	5.9	28	31	315	37	12	315	41	13	
13	9.6	28	39	450	178	40	450	172	38	
14	4.2	29	29	205	0	0	205	0	0	
15	1.6	28	27	85	0	0	85	0	0	
16	5.5	26	26	254	3	1	254	0	0	
17	4.8	24	32	232	119	51	232	86	37	
18	7.2	28	31	340	81	24	340	75	22	
19	3.1	29	29	143	0	0	143	0	0	
20	8.2	27	33	354	169	48	354	135	38	
21	10.5	28	38	482	266	55	482	230	48	
22	11.2	29	41	510	275	54	510	246	48	
23	6.2	29	34	265	102	38	265	91	34	
24	9.3	28	29	400	173	43	400	102	25	
25	10.8	29	39	479	269	56	479	217	45	
26	10.0	29	37	430	200	46	430	150	35	
27	9.3	29	36	397	187	47	397	181	46	
28	4.1	29	29	189	0	0	189	0	0	
29	6.9	28	33	295	124	42	295	113	38	
30	0.9	28	29	53	0	0	53	0	0	
31	4.4	28	28	191	11	6	191	11	6	
Totals	6.7	28	33	9544	3204	34	8733	2730	31	

Julian Date February	Time Interval	Degree Days (°F)	House Heating Demand (MJ)				Time Interval Analysis	Average Hourly Heating Demand MJ/Hour
			Total	Solar	Gas	% Solar		
32	1415-2351	35	117	38	79	33	8	14.90
33	0-2345	33	321	148	174	46	20	15.85
34	0-2351	29	324	167	15e	52	22	14.64
35	0-2345	32	345	227	118	66	24	14.39
36	0-2345	29	323	275	48	85	20	16.45
37	0-2358	31	376	191	186	51	24	15.54
38	0-2345	32	363	144	220	40	24	15.14
39	0-2347	39	333	0	333	0	23	14.73
40	0-2355	40	285	24	261	8	20	14.49
41	0-2345	24	259	123	136	47	20	13.08
42	0-2345	36	375	239	136	64	23	16.03
43	0-2359	47	351	0	351	0	24	14.80
44	0-2345	47	419	178	241	42	24	17.83
45	0-2359	41	344	159	186	46	20	16.96
46	0-2345	41	414	225	188	54	23	17.63
47	0-2345	50	345	49	296	14	21	16.20
48	0-2358	52	383	139	245	36	22	17.39
49	0-2345	49	448	251	197	56	23	19.35
50	0-2357	40	435	269	167	62	24	18.37
51	0-2345	41	274	11	263	4	19	14.48
52	0-2345	33	365	206	159	56	23	15.71
53	0-2345	32	395	348	47	88	24	16.47
54	0-2345	30	418	418	0	100	23	17.94
55	0-2345	24	220	220	0	100	15	14.68
56	0-2346	29	425	390	36	92	24	17.71
57	0-2359	29	253	74	179	29	20	12.52
58	0-2345	26	281	76	205	27	24	11.88
59	0-1600	31	190	58	132	31	16	12.28
Totals		1002	9383	4646	4737	50	597	15.73

Julian Date February	Solar Insolation $MJ/m^2/Day$ Cum. Horizontal	Storage Tank Temp Daily		Ground Array Performance			Roof Array Performance			Remarks
		Start °C	Finish °C	MJ Available	MJ Collected	%	MJ Available	MJ Collected	%	
32	1.4	31	31	65	13	21	65	11	17	
33	10.1	28	39	402	225	56	402	174	43	
34	8.4	29	31	361	88	24	361	75	21	
35	12.1	28	43	503	280	56	503	282	56	
36	10.8	29	38	451	193	43	451	170	38	
37	7.5	29	34	303	131	43	303	117	39	
38	8.4	29	32	327	117	36	327	114	35	
39	3.0	29	28	126	0	0	126	0	0	
4[illegible]	7.5	27	29	294	87	30	294	73	25	
[illegible]	12.6	28	39	499	250	50	499	222	45	
42	8.0	29	34	304	118	39	304	120	40	
43	6.3	29	28	238	0	0	238	0	0	
44	10.1	27	33	378	219	58	378	149	39	
45	11.2	28	33	403	225	56	403	166	41	
46	10.9	29	36	391	195	50	391	179	46	
47	5.6	28	29	206	44	21	206	31	15	
48	5.8	28	34	206	166	80	206	127	62	
49	11.1	28	37	398	232	58	398	154	39	
50	12.2	31	33	436	195	45	436	130	30	
51	6.3	29	31	219	33	15	219	5	2	
52	14.2	28	41	494	335	68	494	205	41	
53	14.5	29	44	505	320	63	505	264	42	
54	15.2	31	45	521	324	62	521	273	52	
55	7.6	32	46	261	147	56	261	126	48	
56	7.4	36	34	245	42	17	245	43	17	
57	8.5	28	30	280	85	30	280	74	26	
58	8.5	27	30	287	70	24	287	54	19	
59	8.8	27	32	284	94	33	284	81	28	
Totals	8.4	28	34	9388	4230	45	9388	3417	36	

Julian Date March	Time Interval	Degree Days (^oF)	House Heating Demand (MJ)				Time Interval Analysis	Average Hourly Heating Demand MJ/Hour
			Total	Solar	Gas	% Solar		
60	6-2345	33	258	15	243	6	21	12.31
61	0-2356	43	381	19	362	5	23	16.54
62	0-2351	55	427	0	427	0	23	18.82
63	0-2345	41	437	212	226	48	24	18.45
64	0-2345	19	321	176	145	55	22	14.63
65	0-1900	27	217	210	8	96	17	12.85
66	--	--	--	--	--	--	--	--
67	813-2345	29	165	148	17	89	14	11.85
68	0-2345	21	282	282	0	100	19	14.54
69	0-2345	28	289	289	0	100	22	13.26
70	0-2345	33	351	233	118	66	23	15.55
71	0-2359	28	332	306	25	92	22	15.35
72	0-2348	27	302	188	115	62	23	12.96
73	0-2345	32	270	73	197	27	21	12.58
74	0-2349	38	334	118	216	35	24	14.12
75	0-2345	30	337	191	146	57	24	14.04
76	0-2345	20	221	221	0	100	22	9.98
77	0-2345	8	220	220	0	100	23	9.78
78	0-2345	19	252	252	0	100	23	10.92
79	0-2353	18	201	201	0	100	23	8.66
80	0-2345	17	219	219	0	100	20	11.20
81	0-2356	19	261	261	0	100	24	11.02
82	0-2352	32	313	160	153	51	22	14.31
83	0-2345	29	266	65	200	25	22	12.04
84	0-2345	27	292	171	121	59	22	13.13
85	0-2345	23	246	190	56	77	24	10.25
86	0-2345	20	272	272	0	100	24	11.34
87	0-2345	17	240	240	0	100	24	10.00
88	0-2345	18	214	214	0	100	23	9.39
89	0-2345	13	178	178	0	100	23	7.74
90	0-2345	7	103	103	0	100	24	4.28
Totals		801	8201	5428	2773	66	663	12.37

Julian Date March	Solar Insolation $MJ/m^2/Day$ Cum, Horizontal	Storage Tank Temp Daily		Ground Array Performance			Roof Array Performance			Remarks
		Start °C	Finish °C	MJ Available	MJ Collected	%	MJ Available	MJ Collected	%	
60	4.6	28	30	151	54	36	151	43	29	
61	8.1	28	29	258	37	14	258	39	15	
62	8.7	28	28	274	0	0	274	-2	-1	
63	16.5	25	36	512	299	58	512	219	43	
64	13.9	28	42	425	268	63	425	210	49	
65	8.9	30	37	273	99	36	273	95	35	
66	--	--	--	--	--	--	--	--	--	
67	16.0	29	43	473	252	53	473	258	55	
68	8.6	31	43	257	143	56	257	111	43	
69	8.7	33	38	253	110	43	253	106	42	
70	17.5	29	42	505	316	63	505	284	56	
71	12.7	30	35	363	149	41	363	120	33	
72	13.0	29	33	368	145	39	368	146	40	
73	8.9	28	32	253	76	30	253	64	25	
74	11.9	27	31	331	152	46	331	141	43	
75	18.1	28	42	497	327	66	497	290	58	
76	17.0	30	48	464	344	74	464	268	58	
77	13.7	37	47	367	199	54	367	181	49	
78	11.6	38	39	310	61	20	310	48	15	
79	17.1	29	44	450	289	64	450	245	54	
80	15.3	34	51	399	258	65	399	226	57	
81	11.0	42	41	284	20	7	284	31	11	
82	2.3	30	29	58	0	0	58	0	0	
83	7.9	28	30	201	58	29	201	48	24	
84	12.8	26	37	319	215	67	319	133	42	
85	17.0	28	40	421	257	61	421	242	58	
86	20.2	30	46	494	341	69	494	294	60	
87	15.3	36	46	370	197	53	370	187	51	
88	16.7	36	51	399	244	61	399	223	56	
89	19.2	43	54	456	268	59	456	256	56	
90	16.7	49	56	390	168	43	390	167	43	
Totals	10.1	31	40	10575	5344	51	10575	4671	44	

Julian Date April	Time Interval	Degree Days (°F)	House Heating Demand (MJ)				Time Interval Analysis	Average Hourly Heating Demand MJ/Hour
			Total	Solar	Gas	% Solar		
91	0-2345	17	287	287	0	100	23	12.49
92	0-2345	14	273	273	0	100	23	11.89
93	0-2345	17	142	142	0	100	11	12.91
94	0-2345	19	271	271	0	100	22	12.56
95	0-2345	17	222	222	0	100	24	9.43
96	0-2345	16	195	195	0	100	23	8.56
97	0-2345	10	177	177	0	100	22	7.92
98	0-2345	7	163	163	0	100	22	7.51
99	0-2345	25	338	338	0	100	23	14.93
100	0-2345	34	309	309	0	100	21	14.96
101	0-2000	19	181	96	85	53	20	8.94
102	115-2345	19	219	219	0	100	21	10.43
103	0-2345	24	266	229	37	86	24	11.10
104	0-2345	19	173	98	75	57	23	7.51
105	0-2345	20	190	93	96	49	21	8.98
106	0-2346	19	187	29	158	15	24	7.87
107	0-2345	29	188	47	141	25	21	8.77
108	0-2345	27	326	182	143	56	24	13.57
109	0-2345	25	300	300	0	100	23	13.07
110	0-2345	24	304	304	0	100	24	12.94
111	0-2345	21	301	255	46	85	24	12.69
112	0-2345	28	310	310	0	100	21	14.69
113	0-2345	18	215	215	0	100	23	9.54
114	0-2345	20	297	297	0	100	23	12.80
115	0-2345	17	250	250	0	100	23	11.08
116	0-2345	10	155	155	0	100	22	7.14
117	0-2300	7	126	126	0	100	22	5.61
118	545-2345	12	57	57	0	100	12	4.69
119	0-2345	15	181	181	0	100	24	7.55
120	0-2345	23	262	262	0	100	23	11.51
Totals		582	6865	6083	782	89	653	10.51

Julian Date April	Solar Insolation MJ/m^2/Day Cum. Horizontal	Storage Tank Temp Daily Start °C	Finish °C	Ground Array Performance MJ Available	MJ Collected	%	Roof Array Performance MJ Available	MJ Collected	%	Remarks
91	13.1	50	54	304	124	41	304	121	40	
92	15.7	44	48	356	155	43	356	148	41	
93	0.2	43	48	1	0	0	1	0	0	
94	16.6	45	47	378	222	59	378	192	51	
95	15.1	38	43	328	129	39	328	131	40	
96	19.9	34	47	443	268	60	443	253	57	
97	21.5	38	53	468	304	65	468	267	57	
98	11.7	47	55	250	89	36	250	87	35	
99	6.7	50	45	143	0	0	143	0	0	
100	17.3	31	36	370	176	48	370	147	40	
101	20.5	29	41	426	265	62	426	216	51	
102	16.2	33	38	336	145	43	336	121	36	
103	11.9	28	32	239	101	42	239	78	33	
104	11.7	28	33	235	111	47	235	85	36	
105	5.7	27	27	112	6	6	112	7	6	
106	11.9	24	31	239	121	51	239	89	37	
107	13.2	28	32	262	124	47	262	93	35	
108	24.3	28	41	475	305	64	475	264	56	
109	23.2	29	42	454	306	67	454	240	53	
110	17.1	31	37	324	154	48	324	123	38	
111	16.9	28	38	327	200	61	327	184	56	
112	16.8	28	40	316	183	58	316	161	51	
113	20.4	29	39	374	224	60	374	181	48	
114	24.0	30	43	444	293	66	444	228	51	
115	14.6	34	38	274	139	51	274	95	35	
116	18.7	29	38	354	231	65	354	91	26	
117	19.1	32	43	344	227	66	344	135	39	
118	11.9	34	41	207	127	61	207	78	38	
119	16.3	33	40	289	155	54	289	105	36	
120	6.0	31	28	111	0	0	111	0	0	
Totals	12.8	33	40	9183	4883	53	9183	3917	43	

APPENDIX C

NATURAL GAS AND ELECTRICITY CONSUMPTION

NATURAL GAS CONSUMPTION

(ft^3)

STH

M	4340	1450	2320	560
J	3300	1660	1110	530
J	3200	1340	1170	690
A	4280	1330	2290	660
S	3350	1320	1400	630
O	5180	1650	2850	680
N	8950	5260	2880	810
[1] D	18270	12940	4620	710
[2] J 1978	19640	19160	480	--
F	14430	14430	--	--
M	9560	9560	--	--
A	3240	3240	--	--
Total	97,190	73,340	19,130	5270

1 House cleaning

2 DHW and stove turned off

NATURAL GAS CONSUMPTION

(ft^3)

		CH		
M	7830	3620	3680	530
[1] J	7240	1950	4660	630
J	5320	1530	3040	750
A	5730	1540	3640	550
S	6060	2330	3220	510
O	12920	8130	4170	620
N	21650	16440	4430	780
D	28580	23750	4370	460
[2] J 1978	32830	28230	4160	440
F	29690	24610	4640	440
[3] M	28020	21460	6020	540
A	16320	12040	3810	470
Total	202,190	145,630	49,840	6720

[1] Seven house guests for eight days

[2] Three occupants absent one week

[3] Two house guests for six days

ELECTRICITY USAGE

STH

(KWH)

Month	Fan	RA	HC	GA	DHW
M 1977	85.0	89.4	40.0	88.4	4.3
J	0.0	110.6	0.0	116.7	2.5
J	3.0	79.0	0.0	78.7	5.7
A	2.0	83.1	0.0	76.2	3.4
S	11.0	95.4	4.0	82.1	4.1
O	74.9	107.0	19.0	96.0	1.8
N	185.0	90.7	48.3	84.9	3.4
D	209.5	86.7	54.2	78.4	19.4[1]
[2]J 1978	187.7	77.6	39.2	62.6	--
F	257.7	95.5	61.5	100.1	--
M	179.1	94.0	52.3	93.0	--
A	178.4	94.1	53.9	92.1	--

[1] House cleaning

[2] DHW turned off

APPENDIX D

REVISED CALCULATED HEAT LOSS FOR

TYPE 12 QUARTERS (INCLUDES

ENERGY CONSERVATION CHANGES)

Room/ Space	Structural Component	Area Crack L	U	ΔT	Heat Load (Btu/Hr)	Totals (Btu/Hr)
Entry	Floor	44	0.070	50	155	
	Ceiling	44	0.029	72	92	
	B&B Wall	6	0.064	72	27	
	Glazing	56	0.360	72	1452	
	Panels	0	0.300	72	0	
	Door	21	0.330	72	499	
	$Infilt_D$	20	1.000	72	1440	
	$Infilt_W$	42	0.500	72	1512	5177
Living	Floor	270	0.070	50	950	
Room	Ceiling	270	0.029	72	563	
	Brick Wall	132	0.051	72	483	
	B&B Wall	128	0.064	72	590	
	Glazing	84	0.360	72	2177	
	Panels	0	0.300	72	0	
	Infilt	63	0.500	72	2268	7031
Kitchen	Floor	104	0.070	50	366	
	Ceiling	104	0.029	72	217	583
Dining	Floor	104	0.070	50	366	
Room	Ceiling	104	0.029	72	217	
	B&B Wall	16	0.064	72	74	
	Glazing	56	0.360	72	1452	
	Panels	0	0.300	72	0	
	Door	17	0.330	72	404	
	$Infilt_D$	17	1.000	72	1224	
	$Infilt_W$	42	0.500	72	1512	5249
Bath #1	Floor	40	0.070	0	0	
	Ceiling	40	0.029	72	84	
	B&B Wall	40	0.064	72	185	269
Bath #2	Floor	40	0.310	0	0	
	Ceiling	40	0.029	72	84	84
Master	Ceiling	192	0.029	72	401	
Bedroom	Floor	192	0.310	0	0	
	Brick Wall	128	0.051	72	468	
	B&B Wall	32	0.064	72	147	
	Glazing	40	0.	72	1037	
	Panels	16	0.300	72	346	
	Infilt	42	0.500	72	1512	3911

Room/ Space	Structural Component	Area Crack L	U	ΔT	Heat Load (Btu/Hr)	Totals (Btu/Hr)
Hall/ Stairs	Floor	120	0.310	0	0	
	Ceiling	120	0.029	72	250	
	Brick Wall	48	0.051	72	176	426
Bedroom #2	Floor	130	0.310	0	0	
	Ceiling	130	0.029	72	271	
	Brick Wall	180	0.051	72	366	
	B&B Wall	16	0.064	72	74	
	Glazing	40	0.360	72	1044	
	Panels	16	0.300	72	346	
	Infilt	42	0.500	72	1512	3613
Bedroom #3	Same as Bedroom #2					3613
Basement	Floor	720	0.10	20	1440	
	Walls	112	0.10	38	426	1866

GRAND TOTAL: 31,822 Btu/Hr
(13% reduction)

APPENDIX E

"f" CHART CALCULATIONS

WORKSHEET B

SOLAR COLLECTOR PARAMETERS

JOB NO. ____________

(1) $F_R(\tau\alpha)_n$ = 0.63

(2) $F_R U_L$ = 1.4 Langleys/(°F day)

(3) $(\dot{m}C_p)_c / A_c$ = 10

(4) ϵ_c = 0.9

(5) $\frac{(\dot{m}C_p)_c}{(\dot{m}C_p)_{min}}$ = 2.0

(6) $\frac{F_R'}{F_R} = \left\{ 1 + \left[F_R U_L \left(\frac{A_c}{(\dot{m}C_p)_c} \right) \right] \left[\frac{(\dot{m}\,C_p)_c}{\epsilon_c (\dot{m}C_p)_{min}} - 1 \right] \right\}^{-1}$ = .928

(7) $\frac{\overline{(\tau\alpha)}}{(\tau\alpha)_n}$ = 0.92

$F_R' \overline{(\tau\alpha)} = \left(\frac{F_R'}{F_R}\right) \left(\frac{\overline{(\tau\alpha)}}{(\tau\alpha)_n}\right) F_R(\tau\alpha)_n$ = 0.538

$F_R' U_L = \left(\frac{F_R'}{F_R}\right) F_R U_L$ = 1.30

(1) Obtained from y-intercept of η vs $\frac{\Delta T}{I}$ curve (Fig. 2-2 or manufacturer's data) use curve for 488 L/day

(2) Obtained from absolute value of slope of η vs $\frac{\Delta T}{I}$ curve.

(3) Mass flowrate of working fluid through collector, $\dot{m}$, specific heat of fluid C_p, area of collector, A_c

(4) Effectiveness of the collector-tank heat exchanger, if employed, if not employed, use ϵ_c = 1.0

(5) Ratio of heat capacity flowrate of the fluid through the collector to the heat capacity flowrate which is the minimum of the two fluids in the collector-tank heat exchanger, if employed, if not employed, use ratio = 1.0.

(6) Will equal 1.0 if no collector-tank heat exchanger employed.

(7) Use constant = .92 if no better data available.

WORKSHEET C-1

LOAD CALCULATIONS (5)

JOB NO ________________

Heat Loss Rate (L) 15.8 Btu/ft^2 degree-day gross (from Table 3-1) or net

Area (M) 1900 ft^2

Year 19 76

Month	Degree Days (P)	GROSS: Space Heat Load R=(L)x(M)x(P)	GROSS: Hot Water (U)	NET: Space Heat Load (V)=(R x η_w)	NET: Hot Water (W) Q_d x N_o	NET: Total Q_t = (V) + (W)
DEC	1115			33.47x10^6	2.44x10^6	35.91x10^6
JAN	1094			32.84	2.44	35.28
FEB	1048			31.46	2.21	33.67
MAR	964			28.93	2.44	31.37
APR	932			28.88	2.37	31.25
MAY	391			11.74	2.44	14.18
JUN	141			4.23	2.37	6.60
JUL	61			1.83	2.44	4.27
AUG	101			3.03	2.44	5.47
SEP	306			9.19	2.37	11.56
OCT	682			20.47	2.44	22.91
NOV	866			26.00	2.37	28.37
	(1)	(2)	(3)	(4)	(3)	
	Obtained from Heating Plant #1 (last 8 yr avg)				$\sum_{12} Q_t$ = Q_{t_y}	260.84x10^6

(1) From local records or Climatic Atlas of U.S., U.S. Dept. Commerce

(2) Based on fuel used.

(3) From Worksheet C-2, Gross = $\frac{net}{\eta_w}$, η_w = utilization efficiency of heater. May be approximated as constant

(4) η_w = Utilization efficiency of heater. Net space heat may be calculated from heat loss of building or from fuel usage times efficiency of heater. If "L" is net heat loss rate, then "V" = LxMxP (without η_w)

(5) . Units of heat on this Worksheet are in 10^6 Btu

WORKSHEET C-2

DEMAND CALCULATIONS DOMESTIC WATER HEATER

JOB NO ____________

Type Building Single Family Dwelling BR 3 Bath 2

No. of Occupants 4 Use/day-person(1) ____________

Average daily demand, gallons 100 x 8.3 lbs./gal = 830 lbs W

Supply temperature (winter), °F 45 (2) Average water temperature (T_i)

After heating 140 °F = Desired hot water temperature (T_o)

Q_d = daily BTU's to be collected = $W C_p \Delta T = W C_p (T_o - T_i)$

830 lb. (1.0) 95 °F 78,850 Btu/day

Month	(3) Q_d, BTU's required one day	N_o No. of days in month	Net Monthly Average Demand $Q_d \times N_o$
DEC	78,850	31	2.44×10^6
JAN	78,850	31	2.44
FEB	78,850	28	2.21
MAR	78,850	31	2.44
APR	78,850	30	2.37
MAY	78,850	31	2.44
JUN	78,850	30	2.37
JUL	78,850	31	2.44
AUG	78,850	31	2.44
SEP	78,850	30	2.37
OCT	78,850	31	2.44
NOV	78,850	30	2.37
		$\Sigma Q_d N_o = Q_{d_t}$	28.77×10^6

(1) Taken from Chapter 1, DM-3.

(2) Ground water temperature taken as normal daily average temperature from Climatic Atlas of US, US Department of Commerce (Reference 5)

(3) May be approximated as constant, or accuracy may be improved by using different T_i and T_o for each month.

WORKSHEET D-1

MONTHLY SOLAR COLLECTION PARAMETERS

JOB NO ________________

$F_R'(\overline{\tau\alpha})$ = 0.538 (from Worksheet B)

$F_R' U_L$ = 1.30 (from Worksheet B)

Mo.	N_o (days/mo.)	I (lys/day) (3)	S Slope Factor (4)	Air Temp T_a (^oF)	$T_{ref}-T_a$ = (212F-Ta) (^oF)	Q_L (10^6 B/mo.) (1)	$F_1 = N_o F_R' \frac{(\overline{\tau\alpha}) IS(3.69)}{Q_L}$ (ft^{-2}) (1,2)	$F_L = \frac{F_R' U_L (T_{ref}-T_a) N_o (3600)(4.0)}{Q_L}$ (ft^{-2}) (1,2,5)
DEC	31	212	2.3	29	183	35.91	8.35×10^{-4}	3.03×10^{-3}
JAN	31	251	2.0	30	182	35.28	8.98	3.07
FEB	28	383	1.5	28	184	33.67	9.49	2.94
MAR	31	502	1.3	34	178	31.37	1.28×10^{-3}	3.38
APR	30	616	1.2	42	170	31.25	1.41	3.13
MAY	31	698	1.1	52	160	14.18	3.31	6.71
JUN	30	718	1.1	60	152	6.60	7.13	13.3
JUL	31	687	1.1	63	149	4.27	10.80	20.8
AUG	31	608	1.2	62	150	5.47	8.21	16.3
SEP	30	485	1.3	55	157	11.57	3.25	7.81
OCT	31	366	1.5	43	169	22.84	1.48	4.40
NOV	30	255	2.0	36	176	28.37	1.07	3.57

(1) Loads, Q_L, from Worksheet C-1

(2) Factor 3.69 converts langleys/day to BTU/ft^2-day

(3) From Table 1-1 based on location For 40^o N from ASHRAE C#59 for 21st of each month, S=0

(4) From Figure 3-2 based on tilt angle of latitude 40^o + 10^o = 50^o

(5) Factor (4.0) converts hours of sunlight (6 hours) to hours per day (24 hours)

WORKSHEET D-2

FRACTION OF LOAD SUPPLIED BY SOLAR HEAT

JOB NO. ____________________

Month	A_c = 500 ft^2			A_c = 600 ft^2			A_c = ______ ft^2		
	$A_c F_I$ (1)	$A_c F_L$ (1)	f (2)	$A_c F_I$	$A_c F_L$	f (2)	$A_c F_I$	$A_c F_L$	f (2)
DEC	.42	1.51	.24	.51	1.81	.38			
JAN	.45	1.53	.26	.54	1.84	.39			
FEB	.47	1.47	.28	.57	1.76	.45			
MAR	.64	1.69	.47	.77	2.03	.56			
APR	.71	1.57	.65	.86	1.88	.64			
MAY	1.66	3.36	.95	1.98	4.03	1.0			
JUN	3.57	6.63	1.0	4.28	7.96	1.0			
JUL	5.40	10.38	1.0	6.54	12.19	1.0			
AUG	4.11	8.16	1.0	4.92	9.79	1.0			
SEP	1.63	3.91	.95	1.94	4.69	1.0			
OCT	.74	2.20	.55	.87	2.63	.60			
NOV	.54	1.28	.41	.64	2.14	.44			
			.49			.57			

$\bar{f} = \frac{\Sigma Q_L f}{\Sigma Q_L}$ Note: Use Q_L's from Worksheet D-1

STORAGE SIZING

Minimum storage size - DHW one days' usage (Worksheet C-2) V = ____________ gal

Space heat/DHW 1 gal/ft^2 collector V = 1 x A_c = ____________ gal

For non-water, see section 3.6.

Other "rules of thumb"

DHW 1.5 - 2.5 day's usage (the latter with no auxiliary heater) V = ____________ gal

Space heat/DHW 3-5 gal/ft^2 V = 20 x A_c 1000 +1200 gal

(1) F_I and F_L from Worksheet D-1

(2) From Figure 3-1 after A_cF_I and A_cF_L calculated

WORKSHEET B

SOLAR COLLECTOR PARAMETERS

JOB NO. ____________

(1) $F_R(\tau\alpha)_n =$ 0.63

(2) $F_R U_L =$ 1.40 Langleys/(°F day)

(3) $(\dot{m}C_p)_c / A_c =$ 2.84

(4) $\epsilon_c =$ 0.9

(5) $\dfrac{(\dot{m}C_p)_c}{(\dot{m}C_p)_{min}} =$ 1.0

(6) $\dfrac{F_R'}{F_R} = \left\{ 1 + \left[F_R U_L \left(\dfrac{A_c}{(\dot{m}C_p)_c}\right)\right] \left[\dfrac{(\dot{m}C_p)_c}{\epsilon_c(\dot{m}C_p)_{min}} - 1 \right] \right\}^{-1} =$ .948

(7) $\dfrac{\overline{(\tau\alpha)}}{(\tau\alpha)_n} =$ 0.92

$F_R' \overline{(\tau\alpha)} = \left(\dfrac{F_R'}{F_R}\right) \left(\dfrac{\overline{(\tau\alpha)}}{(\tau\alpha)_n}\right) F_R(\tau\alpha)_n =$ 0.550

$F_R' U_L = \left(\dfrac{F_R'}{F_R}\right) F_R U_L =$ 1.33

(1) Obtained from y-intercept of η vs $\dfrac{\Delta T}{I}$ curve (Fig. 2-2 or manufacturer's data)

(2) Obtained from absolute value of slope of η vs $\dfrac{\Delta T}{I}$ curve.

(3) Mass flowrate of working fluid through collector, $\dot{m}$, specific heat of fluid C_p, area of collector, A_c

(4) Effectiveness of the collector-tank heat exchanger, if employed; if not employed, use $\epsilon_c = 1.0$

(5) Ratio of heat capacity flowrate of the fluid through the collector to the heat capacity flowrate which is the minimum of the two fluids in the collector-tank heat exchanger, if employed; if not employed, use ratio = 1.0.

(6) Will equal 1.0 if no collector-tank heat exchanger employed.

(7) Use constant = .92 if no better data available.

WORKSHEET C-1

LOAD CALCULATIONS (5)

JOB NO ____________

Heat Loss Rate (L) 7.83 Btu/ft^2 degree-day gross (from Table 3-1) or net

Area (M) 1900 ft^2

Year 19____

Month	Degree Days (P)	GROSS Space Heat Load $R=(L)x(M)x(P)$	GROSS Hot Water (U)	NET Space Heat Load $(V)=(R x \eta w)$	NET Hot Water (W) $Q_d \times N_o$	NET Total $Q_l = (V)+(W)$
DEC	1115			16.59x10^6	2.44x10^6	19.03x10^6
JAN	1094			16.28	2.44	18.72
FEB	1048			15.59	2.21	17.80
MAR	964			14.34	2.44	16.78
APR	932			13.87	2.37	16.24
MAY	391			5.82	2.44	8.26
JUN	141			2.10	2.37	4.47
JUL	61			0.91	2.44	3.35
AUG	101			1.50	2.44	3.94
SEP	306			4.55	2.37	6.92
OCT	682			10.15	2.44	12.59
NOV	866			12.89	2.37	15.26
	(1)	(2)	(3)	(4)	(3)	
					$\sum_{12} Q_l = Q_{l,t}$	143.26x10^6

(1) From local records or Climatic Atlas of U.S., U.S. Dept. Commerce

(2) Based on fuel used.

(3) From Worksheet C-2, Gross = $\frac{net}{\eta_w}$, η_w = utilization efficiency of heater. May be approximated as constant.

(4) η_w = Utilization efficiency of heater. Net space heat may be calculated from heat loss of building or from fuel usage times efficiency of heater. If "L" is net heat loss rate, then "V" = LxMxP (without η_w).

(5) Units of heat on this Worksheet are in 10^6 Btu

WORKSHEET C-2

DEMAND CALCULATIONS DOMESTIC WATER HEATER

JOB NO. ____________

Type Building ____________ BR ______ Bath ______

No. of Occupants ____________ Use/day-person(1) ____________

Average daily demand, gallons ______ x 8.3 lbs/gal = ____________ lbs W

Supply temperature (winter), °F ______(2) Average water temperature (T_i)

After heating ____________°F = Desired hot water temperature (T_o)

Q_d = daily BTU's to be collected = $W C_p \Delta T = W C_p (T_o - T_i)$

830 lb (1.0) 95 °F 78,850 Btu/day

Month	(3) Q_d, BTU's required one day	N_o No. of days in month	Net Monthly Average Demand $Q_d \times N_o$
DEC	78,850	31	2.44×10^6
JAN	78,850	31	2.44
FEB	78,850	28	2.21
MAR	78,850	31	2.44
APR	78,850	30	2.37
MAY	78,850	31	2.44
JUN	78,850	30	2.37
JUL	78,850	31	2.44
AUG	78,850	31	2.44
SEP	78,850	30	2.37
OCT	78,850	31	2.44
NOV	78,850	30	2.37
		$\Sigma Q_d N_o = Q_{d_t}$	28.77×10^6

(1) Taken from Chapter 1, DM-3.

(2) Ground water temperature taken as normal daily average temperature from Climatic Atlas of US, US Department of Commerce (Reference 5)

(3) May be approximated as constant, or accuracy may be improved by using different T_i and T_o for each month.

WORKSHEET D-1

MONTHLY SOLAR COLLECTION PARAMETERS

JOB NO ____________

$F_R'(\overline{\tau\alpha})$ = 0.55 (from Worksheet B)

$F_R' U_L$ = 1.33 (from Worksheet B)

Mo.	N_o (days/mo.)	(3) I (lys/day)	(4) S Slope Factor	Air Temp T_a (°F)	$T_{ref}-T_a$ = (212F-Ta) (°F)	(1) Q_L (10^6 B/mo.)	(1,2) $F_1 = \frac{N_o F_R' (\overline{\tau\alpha}) I S (3.69)}{Q_L}$ (ft^{-2})	(1,2,5) $F_2 = \frac{F_R' U_L (T_{ref}-T_a) N_o}{Q_L}$ [illegible] (ft^{-2})
DEC	31	212	2.3	29	183	19.03	1.62×10^{-3}	5.90×10^{-3}
JAN	31	251	2.0	30	182	18.72	1.65	5.98
FEB	28	383	1.5	28	184	17.80	1.86	5.74
MAR	31	502	1.3	34	178	16.78	2.47	6.51
APR	30	616	1.2	42	170	16.24	2.80	6.22
MAY	31	698	1.1	52	160	8.26	5.78	11.64
JUN	30	718	1.1	60	152	4.47	10.30	19.17
JUL	31	687	1.1	63	149	3.35	13.23	25.24
AUG	31	608	1.2	62	150	3.94	11.01	21.90
SEP	30	485	1.3	55	157	6.92	5.45	13.11
OCT	31	366	1.5	43	169	12.59	2.75	8.19
NOV	30	255	2.0	36	176	15.26	2.05	6.84

(1) Loads, Q_L, from Worksheet C-1

(2) Factor 3.69 converts langleys/day to BTU/ft^2-day

(3) From Table 1-1 based on location ____________

(4) From Figure 3-2 based on tilt angle of latitude 40 + 10° = 50°

(5) Factor (4.0) converts hours of sunlight (6 hours) to hours per day (24 hours)

WORKSHEET D-2

FRACTION OF LOAD SUPPLIED BY SOLAR HEAT

JOB NO. ________________

Month	A_c = 546 ft^2			A_c = ______ ft^2			A_c = ______ ft^2		
	$A_c F_I$ (1)	$A_c F_L$ (1)	f (2)	$A_c F_I$	$A_c F_L$	f (2)	$A_c F_I$	$A_c F_L$	f (2)
DEC	0.88	3.22	0.46						
JAN	0.90	3.27	0.47						
FEB	1.01	3.13	0.65						
MAR	1.35	3.56	0.83						
APR	1.52	3.40	0.90						
MAY	3.16	6.36	1.00						
JUN	5.62	10.47	1.00						
JUL	7.22	13.78	1.00						
AUG	6.01	11.95	1.00						
SEP	2.98	7.16	1.00						
OCT	1.50	4.47	0.84						
NOV	1.12	3.73	0.65						
		$\bar{f} = \frac{\Sigma Q_L f}{\Sigma Q_L}$	0.73						

Note: Use Q_L's from Worksheet D-1

STORAGE SIZING

Minimum storage size - DHW one days' usage (Worksheet C-2) V = ______________ gal

Space heat/DHW 1 gal/ft^2 collector V = 1 x A_c = ______________ gal

For non-water, see section 3.6

Other "rules of thumb"

DHW 1.5 - 2.5 day's usage (the latter with no auxiliary heater) V = ______________ gal

Space heat/DHW 3-5 gal/ft^2 V = ______ x A_c ______________ gal

(1) F_I and F_L from Worksheet D-1

(2) From Figure 3-1 after $A_c F_I$ and $A_c F_L$ calculated